R 480

Technical Report

COMPACTED-SNOW RUNWAYS IN ANTARCTICA DEEP FREEZE 65 TRIALS

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COMPACTED-SNOW RUNWAYS IN ANTARCTICA — DEEP FREEZE 65 TRIALS

Technical Report R-480

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by

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ABSTRACT

The Laboratory conducted snow-compaction investigations on the Ross Ice Shelf adjacent to McMurdo Sound during Deep Freeze 65 following investigations made during Deep Freeze 61 through Deep Freeze 64. A 150- by 6,000-foot runway was constructed by adding a 16-inch layer of compacted snow over an existing layer. Construction was completed on 24 November 1964 and the runway was maintained and repaired for aircraft tests until 14 February 1965. Snowplow carriers used in clearing the runway of drift snow greatly reduced the time required for this operation over previous methods using a snowplane. A 6 by 6 truck-tractor with high-flotation tires served as a prime mover for maintenance equipment, and resulted in large savings in time over use of a size 2 snow tractor. This wheeled vehicle also eliminated damage to the runway surface caused by track vehicles.

The runway was tested early in the season by a 25,000-pound C-47J aircraft with tire inflation pressure of 60 psi; it was tested five times at approximately 2-week intervals by an LC-130F aircraft weighing from 90,000 to 135,000 pounds with tire inflation pressures of 85 to 95 psi. During the first LC-130F tests, intermittent failures occurred in the DF-65 layer of compacted snow due to misses between lanes of snow processed by the mixers and seams of unprocessed snow between the DF-64 and DF-65 layers. These low-strength areas were repaired by reprocessing with the mixers, which brought their strength up to that of the original DF-65 layer.

It was concluded that well-processed snow will support a 125,000-pound LC-130F aircraft with tire inflation pressure of 85 psi during periods of air temperatures to 32°F and snow temperatures to 23°F. The same area will support a 135,000-pound LC-130F with tire inflation pressure of 95 psi during periods of air temperatures to 18°F and snow temperatures to 16°F.

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PART I. INTRODUCTION

Polar ice caps are perennial snowfields. Most land and sea areas in these regions are also covered with a light- to moderate-snow blanket during the fall, winter, and spring. Techniques and equipment to utilize this snow as a building material for emergency and temporary roads, runways, and skiways can materially improve year-round operations in these regions.

Since 1961, high-strength, compacted-snow areas capable of supporting fully loaded LC-130F type aircraft on wheels have been developed on the deep snow of the Ross Ice Shelf near McMurdo Station, Antarctica. The cold-processing, snow-compacting techniques used in this development have also been used for building vehicle roads and parking areas on the annual and perennial fields around McMurdo Station, and some of them for building skiways on the deep snow near McMurdo Station and at the Pole Station.

This report covers the construction, maintenance, and repair of a 150-foot-wide by 6,000-foot-long compacted-snow area on the Ross Ice Shelf during the austral summer of Deep Freeze 65 (DF-65). Between early December 1964 and mid-February 1965, this area was tested with aircraft up to a gross weight of 135,000 pounds and a main wheel tire inflation pressure of 95 psi.

BACKGROUND

Cold-processing, snow-compacting techniques developed by the U. S. Naval Civil Engineering Laboratory (NCEL)[1] were first used in Antarctica during DF-61 to investigate the feasibility of building vehicle roads on snow-covered sea ice in the vicinity of McMurdo Station.[2] At the same time a test was conducted on the deep snow of the Ross Ice Shelf near McMurdo to determine the feasibility of these techniques for building runways for wheeled aircraft in Antarctica. Between December 1960 and February 1964, DF-61 through DF-64, snow-compaction trials[3] were conducted at this location during the austral summer of each year utilizing naval construction personnel under the technical direction of the Laboratory. During these trials, construction of intermittent areas of compacted snow capable of supporting aircraft weighing up to 100,000 pounds with main wheel tire pressures of 90 psi was achieved, but zones of low-strength snow prevented takeoffs and landings with aircraft weighing over 25,000 pounds and having main wheel tire pressures over 60 psi.

SNOW AS A CONSTRUCTION MATERIAL

The metamorphic process of snow under natural conditions and the consequent beneficial effect on its structural properties greatly influenced the Navy's investigation of snow as a construction material. Following Operation High Jump,[4] the phenomenon of metamorphism led to the development of in-place, cold-processing compaction techniques and special equipment to accelerate the natural processes involved.

Unlike sea ice, which is formed in place and whose density varies between 0.85 and 0.92 gm/cc, depending upon its age and the conditions surrounding its formation, snow is deposited on the surface in particle form with a density ranging between 0.01 and 0.20 gm/cc. Being thermodynamically unstable, these particles change from flakes to granular crystals and, as the natural metamorphic process continues, the density of the snow mass increases. In time, it produces a dense, coarse-grained snow with densities greater than 0.30 gm/cc. Continued metamorphism produces glacial ice.[5]

Hardening is also a natural metamorphic process which causes marked changes in the mechanical properties of snow, independent of those produced by a change in density alone. In the hardening process, the individual crystals become bonded to each other by ice bridges. The process of hardening requires the presence, at least temporarily, of an excess of either liquid or vapor beyond that supportable by the heat content of the snow mass.

Since snow crystals, because of their interrelation and bonding characteristics, must always tend to be in thermodynamic equilibrium with the environment, the properties of density, grain size, and strength are time-dependent. Therefore, the time-independent relationships normally applied to problems involving the strength of materials cannot be directly applied to snow.[6]

REQUIREMENTS FOR SNOW COMPACTION IN ANTARCTICA

The United States terminal for all continental air operations in Antarctica is McMurdo Station, a coastal installation on the Ross Sea, 2,400 miles from New Zealand. (Inland U. S. stations in Antarctica are also supported principally by air.) Since Deep Freeze I in 1955, runways on sea ice have been used at McMurdo for wheeled aircraft making the New Zealand flights. Preparation of the ice runways each year has necessitated the removal of thousands of cubic yards of snow covering them. Then, in the relatively warm months of December and January, the runways are frequently closed because of hazardous surface conditions resulting from rapid, differential deterioration of the ice. Occasionally, during breakup of the sea ice, the runways have been lost or so seriously jeopardized that continued air operations were unsafe.

Following the International Geophysical Year which ended in 1959, the need for a permanent year-round air facility at McMurdo Station to support the continuing United States Antarctic Research Program became paramount. An investigation in the McMurdo area showed that the only open, fairly stable area suitable for a year-round airport complex at McMurdo was on the Ross Ice Shelf, a few miles southeast of Ross Island. A study of this area, which was assigned to NCEL, included a determination of the feasibility of compacted snow for runways, taxiways, parking aprons, warmup pads for heavy aircraft on wheels, and service roads for passenger and cargo vehicles on wheels. The investigation also included studies on prolonging the life of these roads and runways and the facilities required to support an airport on a deep snow field.

An experimental compacted-snow area developed under this study on the Ross Ice Shelf during the summer of DF-62 was used extensively for full-load LC-130F aircraft ski takeoffs following breakout of the sea ice on McMurdo Sound in early February 1962. Subsequently, at the request of the Commander, Naval Support Forces, Antarctica, the Chief of Naval Operations established an operational requirement for the development of engineering techniques for compacted-snow runways capable of accepting wheeled aircraft with gross weights up to 155,000 pounds. Sufficient support of the development to insure optimum annual progress at McMurdo Station was authorized, as was an investigation, contingent on progress, of the feasibility of compacted-snow runways for wheeled aircraft at Byrd and South Pole Stations.

To achieve the objectives of this operational requirement within a reasonable period of time, NCEL envisioned a year-round field effort between October 1962 and February 1965. Based on this premise, a task schedule and cost estimates were prepared around a continuing military-civilian field team functioning during that period. However, the Chief of Naval Operations, in approving the NCEL plan, specified that the construction effort was to be accomplished by military personnel deployed to the area during the austral summer.

TEST PLAN FOR DF-65

The DF-65 NCEL Ross Ice Shelf test site was located about 6 miles from McMurdo Station (Figure 1). The same area was used for the DF-61 through DF-64 trials.[3] In DF-61, a single-layer, compacted-snow test area, 200 feet wide by 4,000 feet long by 20 inches thick, with its major axis in the east-west direction, was constructed near the edge of the Ross Ice Shelf. In DF-62, two additional layers of compacted snow were built on top of the DF-61 layer (Figure 2). The first one was 150 feet wide by 5,000 feet long by 16 inches thick; the second, 150 feet wide by 4,000 feet long by 16 inches thick. No work was done on this area in DF-63; instead, a second test area, 150 feet by 7,000 feet, was located in line with the original area and 2,000 feet from its eastern end (Figure 1). Late in the summer of DF-63, these

two areas were connected with a 16-inch-thick layer of compacted snow, producing a test area 14,000 feet long. Although connected in one continuous strip, the area was treated as two 7,000-foot-long test areas. For identification, the end including the early efforts was designated the 0-70 area, and the new one the 70-140 area. In DF-64, little work was performed on the 70-140 area, but a new 150-foot-wide by 7,000-foot-long by 20-inch-thick layer was added to the 0-70 area.

DF-65 Trials

Early in the summer season of DF-65 a 150-foot-wide by 6,000-foot-long by 16-inch-thick layer of compacted snow was scheduled to be built on top of the DF-64 layer in the 0-70 test area. Since 1,000 feet of the 0-70 area had broken off in February 1964, it was redesignated the 10-70 area for the DF-65 trials. The drift snow that collected in this area between March and October 1964 was to be used as the primary source of material for the DF-65 layer. The depth and distribution of the winter drift would be determined in mid-October 1964, and the area graded and leveled for compaction by early November. If required, blown snow from borrow pits along the edges of the area would be added to obtain a 24-inch depth of snow for compaction.

Compaction of the DF-65 layer was scheduled for November in order to test it with aircraft under a wide range of summer conditions. The method for compacting would be the four-pass mixer process developed for the new model 36/42 snow mixers in the February 64 test strip on the 70-140 area,[3] followed by five passes with the snow-compaction roller.[1] Within 3 to 5 days, or as soon as hardness would permit, the compacted snow was to be surface-hardened with a 9-ton, 13-wheel, pneumatic-tired roller. For maximum surface-hardening, not less than 10 passes were to be made with this roller.

A cross section through the 10-70 area as planned for DF-65 is shown in Figure 2. The western half of the area would consist of five layers of compacted snow, for a total depth of 88 inches; the eastern half would consist of three layers, for a total depth of 52 inches. Previous tests[3] indicated that the 52-inch thickness would be more than adequate for the anticipated aircraft loads provided good bonding was achieved between the DF-64 and DF-65 layers.

In planning only a single layer of compacted snow on the 10-70 area in DF-65, its finished surface would be 8 or more inches below the natural surface. This condition, it was realized, would accelerate the accumulation of drift snow on the test area during the summer season. Early completion for a maximum of aircraft testing, however, was considered more important than adding a second layer to minimize drifting. Maintenance procedures to remove this drift were included in the test plan.

After construction, the 10-70 area was to be maintained and tested with available aircraft during the remainder of the DF-65 summer season.

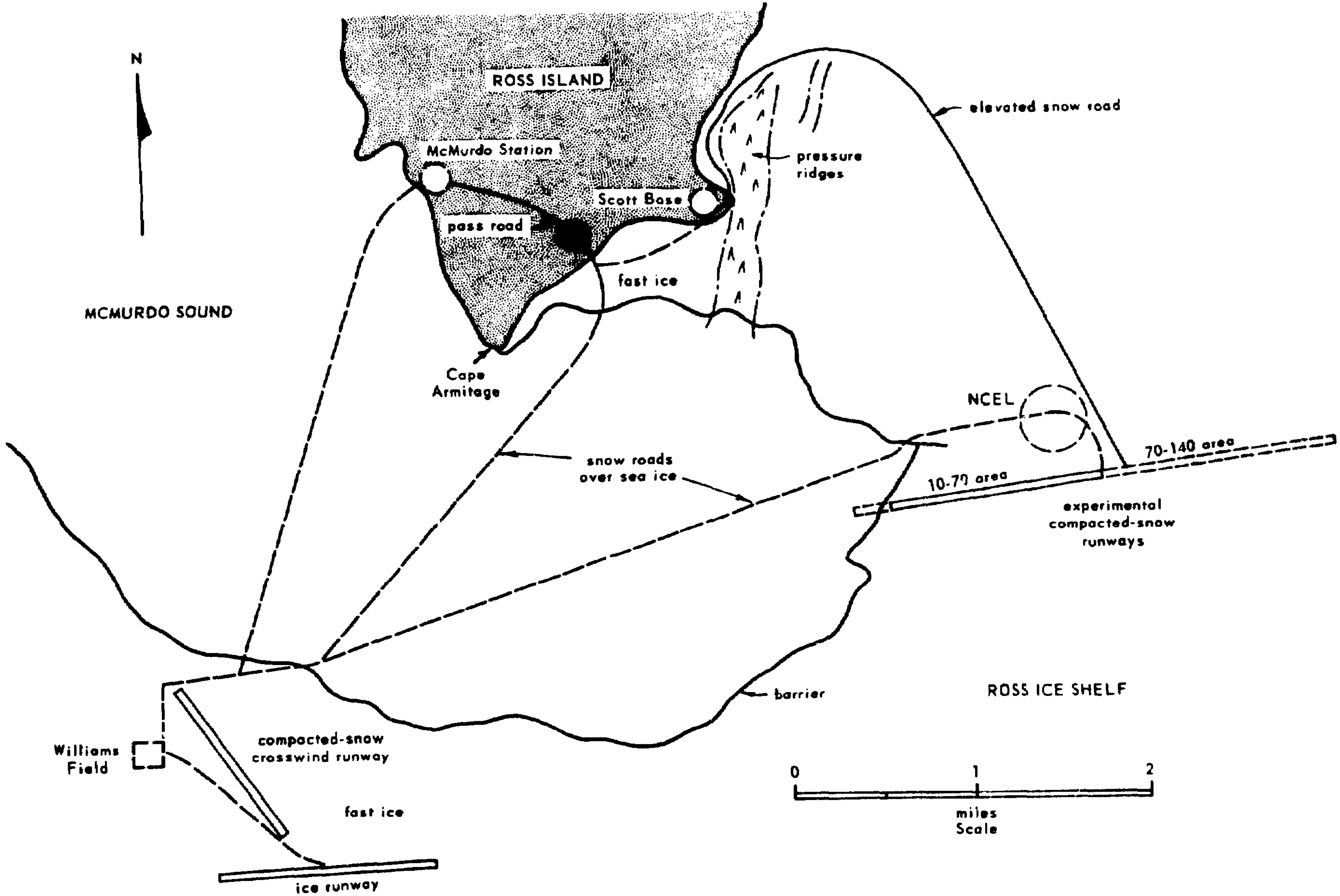


Figure 1. Map of the McMurdo area in DF-65.

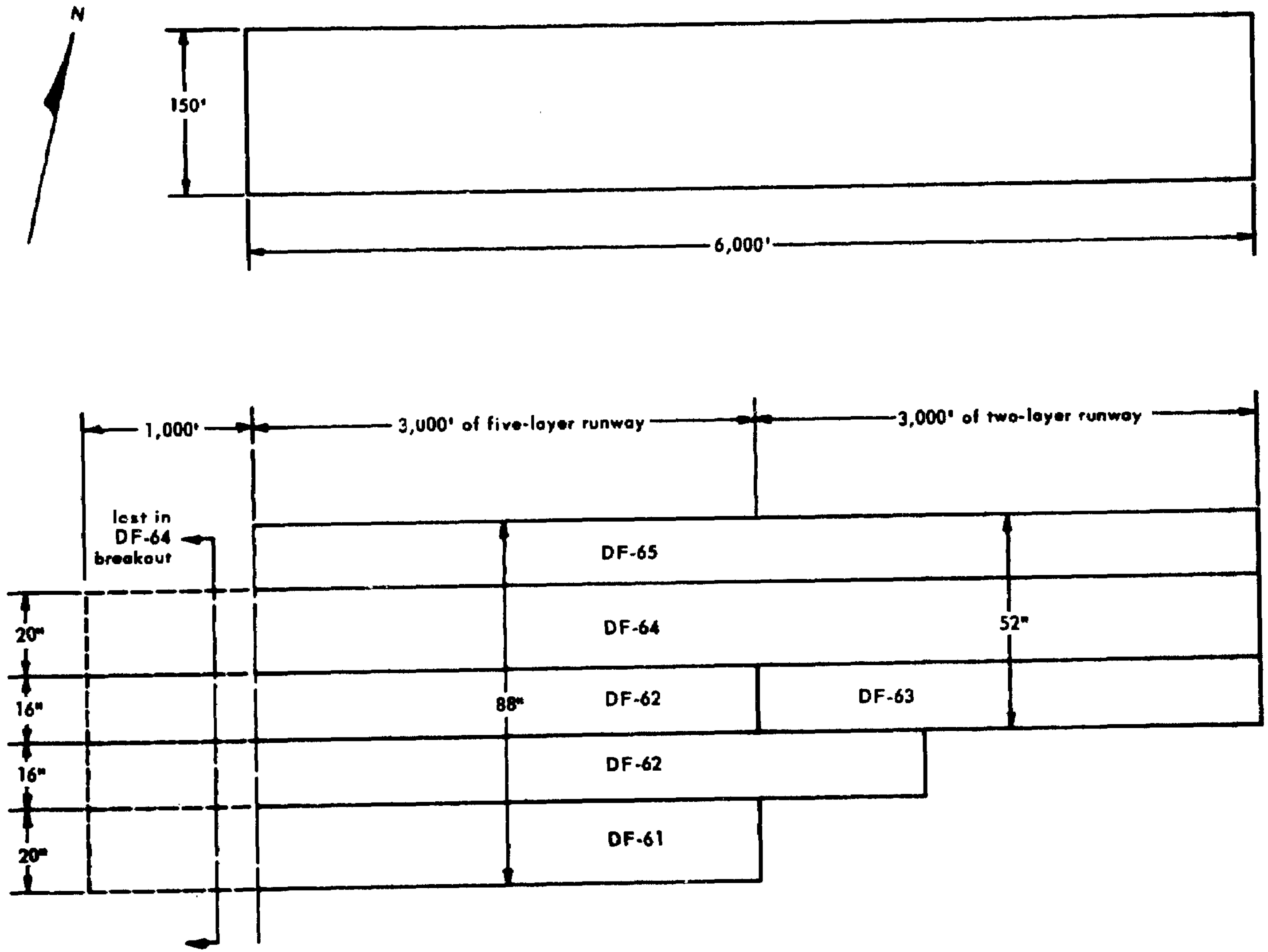


Figure 2. Longitudinal cross section and plan of the 10-70 test area for DF-65.

Personnel

Both technical and construction personnel for the DF-65 trials were to be provided by NCEL. A six-man team would be deployed to Antarctica in mid-October to dig out and service the construction equipment. Seven more men were to follow a week later. In addition to this 13-man field team, the Antarctic Support Activities (ASA) was directed to supplement the NCEL team with a rated Navy cook for the camp at the test site, and Mobile Construction Battalion Six was to assign two nonrated construction personnel to support the field work.

The civilian construction personnel selected for the trials were experienced in operating conventional equipment, but had no cold weather experience. Also, they were totally unfamiliar with the snow-compaction equipment and techniques. The civilian mechanic, however, had served with the field team in DF-64, so was familiar with the equipment and the facilities for repair and maintenance.

Equipment

Much of the snow-compaction equipment for the DF-65 trials had been received late in the DF-64 season. The two model 36/42 mixers, the two snowplows mounted on 40-foot carriers,[7,8] and one size 2 snow tractor[9] were new. A second size 2 snow tractor for the trials had been used without overhaul since 1959; it was in fair condition. In mid-December, a 6 by 6 truck-tractor with high-flotation tires[10] was to be added to tow the surface-hardening and maintenance equipment. Its addition was intended to minimize surface damage to the compacted snow during these operations and, if possible, to speed up maintenance. A new 80-foot snowplane was also to be added in mid-December for better grading and leveling of the test area; it was to replace the 40-foot snowplane[11] used in the previous trials. The snow rollers[12] and drags[13] for the DF-65 trials had been operated for several seasons; they were in fair condition.

TEST PROCEDURES

Both physical-property and aircraft tests were to be made on the DF-65 snow runway. Physical-property tests would include strength measurements, temperature, and density. Strength measurements were to be made principally with the NCEL-type confined-shear test apparatus; checks were to be made with a Rammsonde cone penetrometer developed for testing hardness of snow by the U. S. Army Cold Regions Research Laboratory (CRREL). Aircraft tests would include wheeled taxi tests and, if feasible, landings and takeoffs with aircraft of increasing size and weight. The procedures for these tests were to generally follow those outlined in NCEL Technical Report R-113.[14]

Rammsonde Cone Penetrometer

The CRREL-type Rammsonde cone penetrometer, which was used extensively by NCEL for strength measurements on compacted snow prior to DF-63, gives a hardness index based on the average resistance to penetration. The index has no true physical value, but it does show the relative hardness of snow not only at the surface but also in depth. The device consists of a cone-tipped rod that is manually driven into the snow with a drop hammer. The basic CRREL unit consists of a 1-meter rod fitted with a 1-1/2-inch-diameter cone tip and a 70-cm hammer guide. Two sizes of hammers are provided for driving the rod into the snow — one weighing 1 kilogram and the other 3 kilograms. One-meter rod extensions are also provided for use in deep snow. To speed up sampling of compacted snow, NCEL developed a 1-inch-diameter cone-tipped Rammsonde. Numerous comparative tests using the two sizes of hammers and the 1-1/2-inch cone in adjacent areas of snow showed no linear correlation between the results. The same was true for the two tip sizes. As a result, curves were developed by NCEL to correlate the results of all Rammsonde tests, regardless of tip size and hammer weight, to the equivalent of an index number using a 1-1/2-inch-diameter tip and a 1-kilogram hammer. The index number is identified with the suffix "R."

Tentative curves[14] were developed by NCEL relating the Rammsonde hardness index "R" to the load-carrying capacity for increasing depths of compacted snow for aircraft with varying main-wheel tire pressures. These curves, which were subject to refinement as more data became available, were based on the analysis of several failures during aircraft wheel taxi tests on two experimental snow runways developed by the Laboratory on the Greenland Ice Cap between 1952 and 1954.[15, 16] These failures and those observed during aircraft wheel taxi tests on the DF-61 through DF-64 compacted-snow areas[3] were all punching failures, or wheel breakthroughs, directly under the main wheels of the aircraft. Regardless of length, only the snow directly under the wheels was displaced in these failures. Examination showed the snow was sheared around the perimeter of the wheel contact area and that the snow under the wheel was disaggregated and either pushed down into the softer underlying snow or thrown out of the wheel track.

Confined Shear

To relate the shear strength of snow to the moving wheel loads of aircraft, NCEL developed a confined-shear test apparatus for compacted snow in 1962.[17] This apparatus, modified and tested extensively during the DF-63 trials, was designed to receive 1- to 3-inch-long compacted-snow core specimens obtained with a 3-inch-diameter CRREL ice coring auger. The shear strength was obtained by placing the specimen in a confining cylinder and applying a shearing force through heads positioned to align the shearing edges of the device. The specimens

fitted the cylinder snugly without binding and the heads fitted loosely, but did not allow the specimen to deflect other than vertically. Force, applied to the heads with a hydraulic plunger mounted on a soil-type compression tester frame, was measured with a load cell resting on the lower plate of the compression tester frame. It was recorded directly with time on a strip recorder.

Load-Carrying Capacity

Tests during the DF-64 trials showed that 3-inch-long core specimens or 9 square inches of shear area gave the most consistent results. The confined-shear strength for individual core specimens was converted to pounds per square inch (psi), and the total resistance to confined shear for a given location and mat thickness was obtained by summarizing the individual strengths for each 3-inch increment of compacted-snow thickness in the test locations. Analysis of the DF-63 data indicated that the load-carrying capacity of compacted snow in pounds per square inch of surface area, regardless of its thickness and temperature, was about one-fourth of its total resistance to confined shear. Examination of compacted snow by confined shear around aircraft wheel breakthroughs during the DF-64 trials confirmed this relationship.

The DF-63 and DF-64 tests showed that confined shear provided a more precise index of strength in compacted snow than the Rammsonde. As a result, it was selected as the primary method for measuring the strength of compacted snow in the DF-64 trials. Also, pending further refinement with additional data, one-fourth of the total resistance to confined shear in pounds per square inch of surface area at each test location was to be referred to as its load-carrying capacity in pounds per square inch.

PART II. CONSTRUCTION, MAINTENANCE, AND REPAIR

Before constructing the DF-65 layer on the 10-70 area, tests were made in early November 1964 to determine the operational characteristics of the new model 36/42 snow mixer.

The DF-65 layer was compacted during November. After completion, the surface of the 10-70 area averaged 1.3 feet below the natural surface, necessitating frequent removal of drift snow to keep the area open for aircraft testing during the remainder of the summer season. Punching failures, or wheel breakthroughs, occurred in the DF-65 layer in each aircraft test between 6 December and 24 January; these were repaired after each test.

MODEL 36/42 SNOW MIXER TESTS

Two 300-foot-long by 8-foot-wide (one mixer width) test lanes were made in the natural snow near the 10-70 area to determine the mixer train (tow tractor and snow mixer) travel speeds for selected cutting depths with the two new model 36/42 snow mixers. Tests on both mixers were necessary as one was fitted with a 36-inch-diameter rotor and the other with a 42-inch-diameter rotor. At the time of these tests, the average hardness in the top 24 inches of natural snow was 130 R and the average density 0.36 gm/cm^3. Each mixer made four consecutive passes in its allotted lane. Maximum travel speeds were established by gradually increasing tractor engine speed to the point of stalling. The cutting depths and travel speeds developed from the tests are given in Table 1.

Based on these tests, the following sequences of mixer passes were selected for each depth-processing lane on the DF-65 layer. At a travel speed of 128 fpm, the mixer with the 42-inch rotor cutting to a depth of 24 inches in first gear followed by the mixer with the 36-inch rotor cutting to a depth of 20 inches in second gear were to make the first (breaking) and second processing passes, respectively, traveling in tandem along the entire 6,000-foot length of the area. Then, at a travel speed of 98 fpm, the mixer with the 42-inch rotor cutting to a depth of 18 inches followed by the mixer with the 36-inch rotor cutting to a depth of 16 inches in fourth gear were to made the third and fourth passes, respectively, by returning in tandem to the opposite end of the area in the same lane. After each lane was processed four times, a new lane would be started. To avoid processing misses, the new lane would overlap the previous lane about 2 feet.

Table 1. Cutting Depth Versus Travel Speed Tests With Model 36/42 Mixer

Processing Pass	Mixer Gear No.	Rotor		Maximum Travel Speed (fpm)
		Cutting Depth (in.)	Peripheral Speed (1,900-rpm engine speed) (fpm)	
Mixer with 36-in.-diam rotor:				
First (breaking new material)	1	24	1,381	128
Second	2	20	2,688	128
Third	3	18	4,672	128
Fourth	4	16	5,847	98
Mixer with 42-in.-diam rotor:				
First (breaking new material)	1	24	1,606	128
Second	2	20	3,146	128
Third	3	18	5,467	98
Fourth	4	16	6,842	78

CONSTRUCTION OF THE DF-65 LAYER

Precompaction Preparations

Winter snow drift on the 10-70 area ranged from 22 to 31-1/2 inches deep with the heaviest drift along the south or upwind edge of the area (Figure 1). In early November, its average hardness was 130 R and its average density 0.36 gm/cm^3. As this hardness and this density compared favorably with those of roller-packed snow at the same location in December and January during the previous trials,[3] it was elected to only remove the excess drift and level the area prior to compaction. Normally, snow being prepared for compaction[1] is graded, rolled, and leveled repeatedly until the depth of fill is uniform and the surface level and moderately hard. The snowplane[11] and the snowplow carriers[7] were used to grade and level the drift snow on the 10-70 area. About 55 machine-hours were required to accomplish this work.

Compaction

Compaction of the DF-65 layer started on 10 November using a four-pass tandem snow-mixer, depth-processing technique, followed by five passes with the snow-compaction roller. Including turnarounds, four-pass processing of each mixer lane required about 2 hours and 15 minutes for an average travel speed of 45 fpm for complete processing.

Initially, all four passes in each new lane overlapped about 2 feet on the previous lane. As the difference in elevation between the processed and unprocessed snow was 8 inches, the mixers worked beyond their transverse leveling adjustment until the final pass was made on the new lane. With this difference, the mixer trains tended to sideslip, necessitating continual realignment of the train. Overcorrection, which was difficult to avoid, resulted in complete misses between the lanes. To solve this problem, the following changes in the processing sequence were made on 12 November:

1. The breaking pass on each new lane was moved over until it abutted, but did not overlap, the finished lane. This placed the tractor and the mixer on a fairly level surface. In this position, the rotor, cutting to a depth of 24 inches, dropped the new lane about 4 inches, making its surface only 4 inches above the adjacent processed lane. This pass also formed a low windrow on the edge of the processed lane.

2. The next pass in the new lane was made with one track of the tow tractor on top of the new windrow on the edge of the processed lane. This placed the mixer, cutting to a depth of 20 inches, in a position to overlap the previous lane 1 to 2 feet,

depending on the alignment of the train. This second pass dropped the snow level in the new lane another 2 inches, making the difference in elevation between the two passes only 2 inches. This pass also formed a new low windrow on the processed lane.

3. The third and fourth mixer passes, cutting to depths of 18 and 16 inches, were made in the lane formed by the second mixer pass, thus placing them in a position to also overlap the previous lane 1 to 2 feet, depending on alignment. These two passes dropped the snow level in the new lane 2 more inches, making it level with the previous lane.

4. The low between-lane-processing windrows gained strength fairly rapidly under the prevailing temperatures (Figure 3). As it was necessary to spread and level such windrows with a leveling drag,[13] processing was interrupted after completion of two new lanes to perform this task. Four passes of the drag were required. A tractor was required to tow the drag for the first two passes, but a power wagon fitted with high-flotation tires[18] had sufficient power to make the last two.

Compaction of the DF-65 layer was started along the south side of the 10-70 area (Figure 2) on 10 November and advanced north across the area as the work progressed. Good visibility and excellent depth perception prevailed on the first day of processing. Three four-pass mixer lanes were processed and rolled with the snow-compaction roller on the first day. The finished strip of processed snow was 20 feet wide.

Four lanes were also processed on 11 November, but visibility and depth perception became progressively worse as the day advanced under an overcast sky. Sideslip caused the mixers to overlap the previous lane about 4 feet. By midmorning, there was a complete loss of depth perception. As a result, the last two mixer lanes on 11 November, which should have advanced the processing 14 feet, were crooked, and their combined width varied from 12 to 16 feet. The finished strip of processed snow on 11 November was 20 feet wide, but detailed examination with a Rammsonde showed there were numerous complete processing misses between the mixer lanes. Because of these processing misses, the 11 November strip, which was located between 16 and 36 feet from the south side, was reprocessed on 16 November. The cutting depth and travel speed for the mixer trains, however, were reduced to compensate for the age-hardness of snow in this strip. The first pass was made in first gear at a rotor cutting depth of 10 inches and a travel speed of 80 fpm. The second pass was in second gear at a rotor cutting depth of 16 inches and a travel speed of 80 fpm. The third and fourth passes were in third and fourth gear, respectively, at a rotor cutting depth of 16 inches and a travel speed of 80 fpm. At these cutting depths and travel speeds the mixers were able to break and reprocess the once-processed snow, but there was a preponderance of large, extremely hard material up to 2 inches in size after reprocessing. There was no noticeable difference in elevation between the reprocessed snow and the once-processed snow after the processing equipment windrows were leveled and the strip was rolled with the snow-compaction roller.

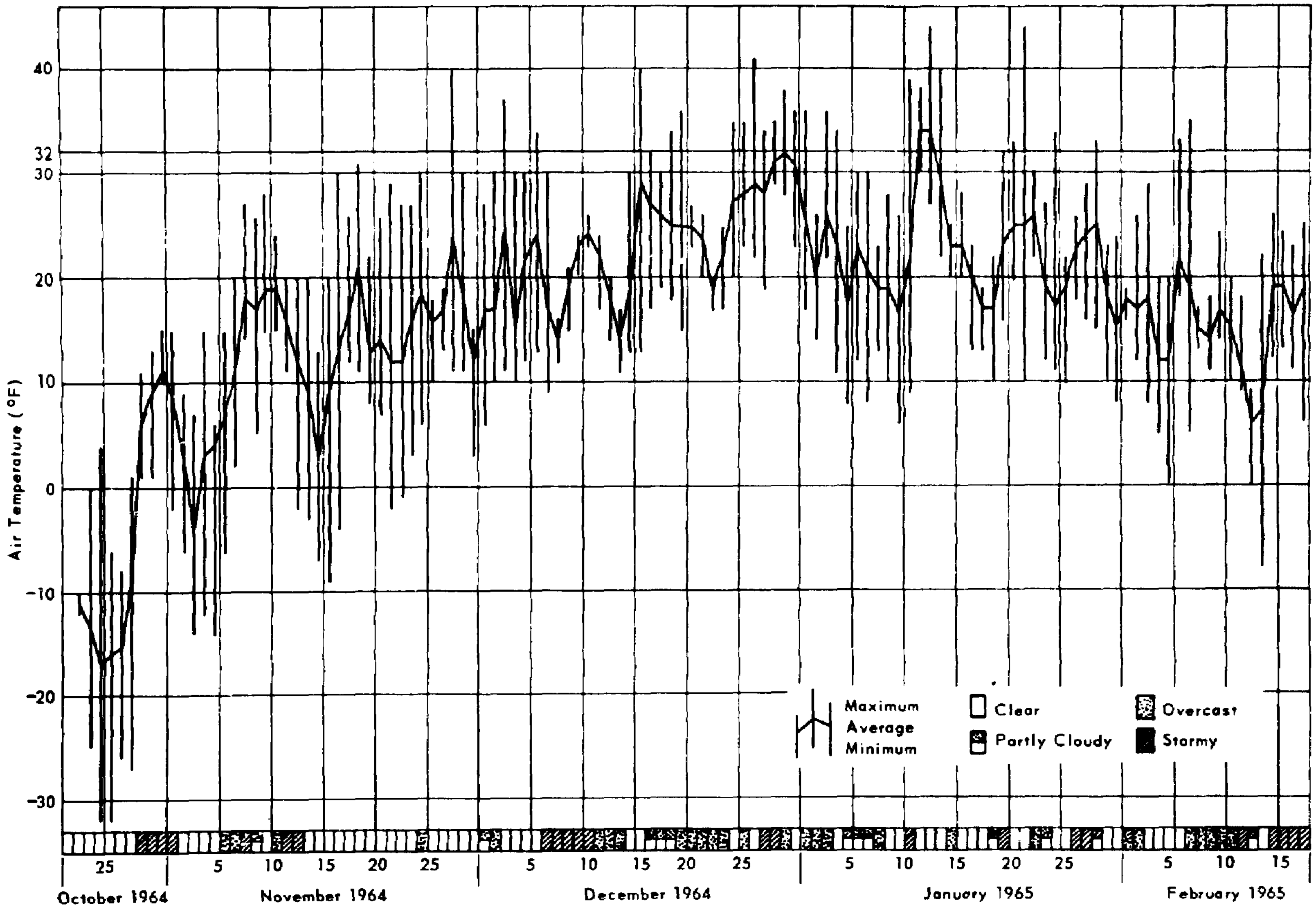


Figure 3. Weather data from NCEL Ross Ice Shelf Camp, DF-65.

The remaining 114-foot width of the area was processed with only minor delays resulting from weather and equipment breakdowns. During the processing, however, it was found that the snow cover in the middle third of the area was not uniform. Instead of being 24 inches deep it varied from 22 to 28 inches. This variation was attributed to insufficient grading and leveling of the area before processing. As a result, where the snow cover was less than 24 inches deep, the rotors would cut into the hard snow of the DF-64 layer and stall the mixer engines unless the mixer operators raised the rotors 2 to 4 inches. When this occurred they slowly worked the rotors back to the proper cutting depth. Varying the rotor cutting depth permitted processing at the selected travel speed for the mixer trains, but as found later, this resulted in seams of unprocessed snow in the DF-65 layer.

Depth-processing and compaction of the processed snow with the snow-compaction roller on the 10-70 area was completed on 24 November. Surface-hardening of the DF-65 layer with 10 passes of the 9-ton, 13-wheel, pneumatic-tired roller was started on 13 November, but not completed until the layer was releveled after being compacted.

Post-Compaction Leveling

After compaction, the transverse profile of the surface undulated from 1 to 2 inches at 20- to 30-foot intervals; this was caused by poor spreading of the processing equipment windrows with the leveling drag. Along the middle of the area, the longitudinal profile undulated noticeably at several locations. These undulations were from 4 to 6 inches above the normal profile and from 50 to several hundred feet long; they were caused by the 22- to 28-inch thickness variation in the snow cover.

The area was releveled with the snowplane between 29 November and 1 December. The transverse profile was leveled with 1- to 2-inch cuts, but the pronounced undulations along the middle of the area required cuts up to 6 inches deep to achieve a moderately level surface. The planing was done between 1300 and 1800 hours each afternoon when the compacted-snow surface was soft enough to cut with the snowplane. Three coverages with the snowplane were required to level the area. The excess snow was graded to each edge and cast off with a snowplow. Five one-way trips with the snowplow carrier were required to remove this material.

Surface-Hardening Rolling

After the surface was releveled, it was rolled with the pneumatic-tired roller and finished with the smoothing drag.[13] Starting at the south side, the first 98 feet, which had been previously rolled with 10 passes of the pneumatic-tired roller, were double-rolled to compact the top 1 to 2 inches of snow disturbed by planing. The remaining 52 feet were rolled with 10 passes to complete the surface-hardening rolling.

LONGITUDINAL AND TRANSVERSE PROFILES

The 10-70 area was surveyed on 20 December to establish its elevation, longitudinal slope, and transverse profile. As the survey was made after the 7-11 December storm (Figure 3), it included the spoil banks developed along each edge of the area when clearing the drift that resulted from this storm.

The ice shelf at the barrier near the west end of the 10-70 area (Figure 1) was 9 feet above the sea ice in McMurdo Sound. Based on this, the elevation on the centerline of the area was established as 13.96 feet at Station 10+00 and 31.44 feet at Station 70+00 (Figure 4), for a difference of 17.48 feet and an average slope of 0.29% on the 6,000-foot-long area. Slope changes along the centerline were as follows:

Location Station	Length (ft)	Difference in Elevation (ft)	Slope (%)
10+00 to 30+00	2,000	5.62	0.28
30+00 to 40+00	1,000	2.48	0.25
40+00 to 50+00	1,000	4.19	0.42
50+00 to 70+00	2,000	5.19	0.26

Transverse profiles at Stations 20+00, 40+00 and 60+00 (Figure 4) show that the surface of the compacted snow varied from a slightly dished surface at Station 20+00 to a fairly flat surface at Station 60+00. After construction, the surface of the compacted snow averaged only 1.3 feet below the natural surface, but clearing the drift from the 7-11 December storm resulted in 100-foot-wide spoil banks along both sides of the area. The compacted surface averaged 3.1 feet below the spoil bank along the south side and 2.2 feet below the spoil bank along the north side.

From time to time, additional drift was removed from the test area between 20 December 1964 and mid-February 1965. A transverse profile across the area at Station 60+00 on 15 February (Figure 5) shows that the south spoil bank was 4.0 feet above the compacted surface, for an increase of 0.9 foot in the 2-month period, but the north spoil bank was only 2.3 feet, for an increase of only 0.1 foot. The profile also shows that the heavy drifting along the south side reduced the usable width of the compacted area from 150 to 130 feet in mid-February.

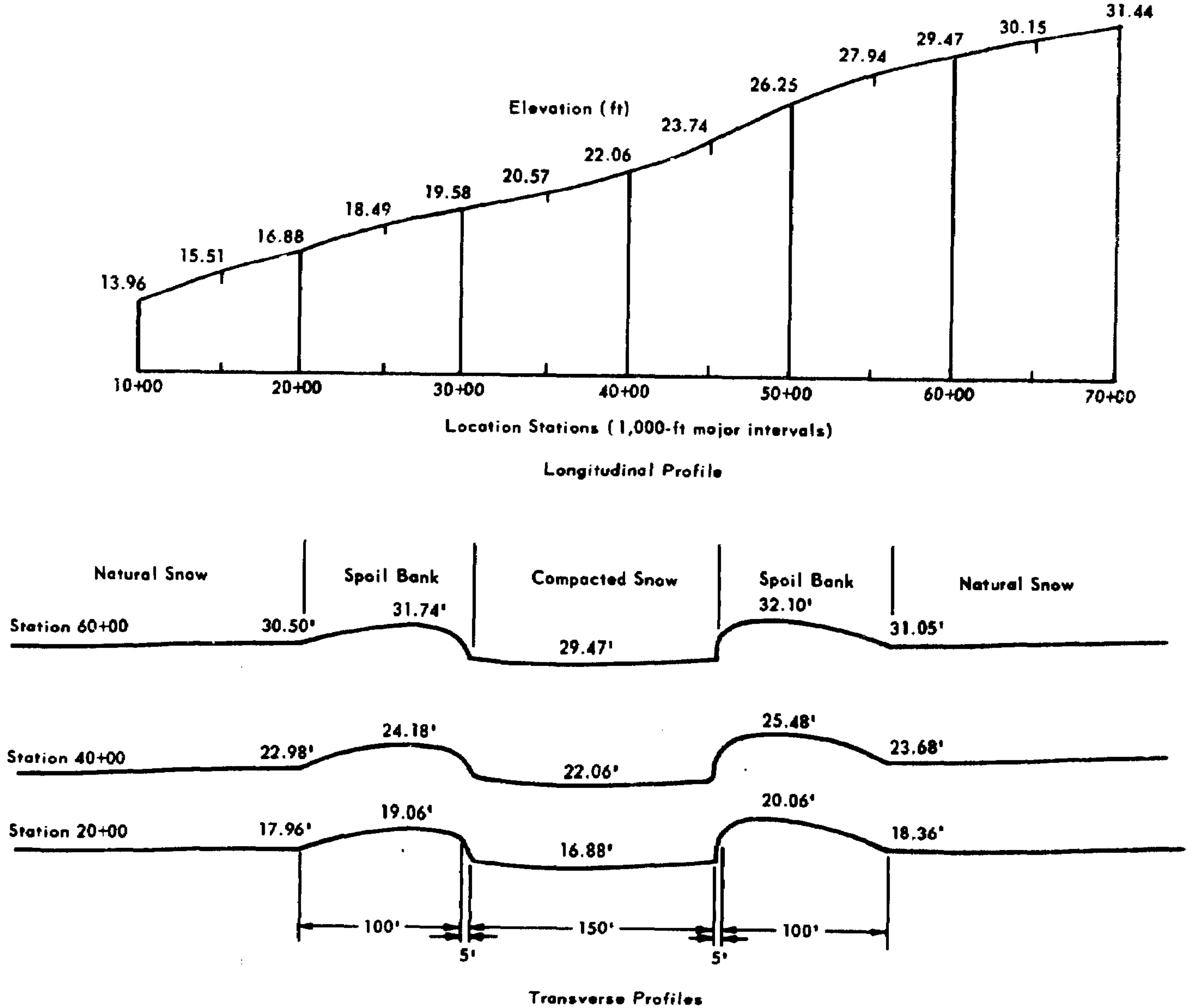


Figure 4. Profiles of 10-70 experimental snow area on 20 December 1964. (All elevations are shown in feet above ice surface on McMurdo Sound.)

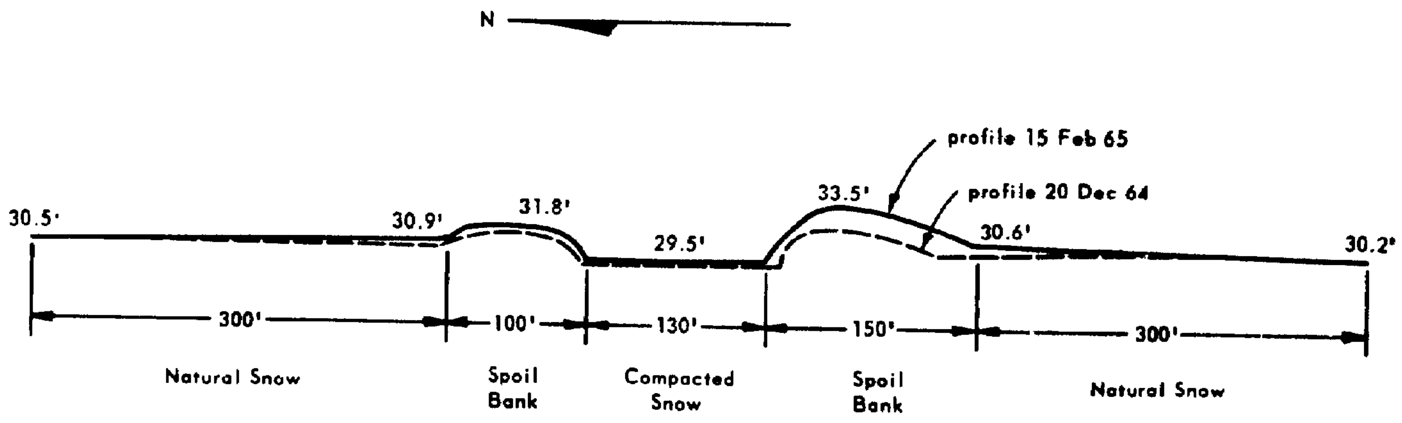


Figure 5. Cross section of 10-70 test area at Station 60+00 on 15 February 1965.

MAINTENANCE

Following construction, the 10-70 area was maintained for aircraft tests from 2 December 1964 to 14 February 1965. Both snow removal and surface finishing were required in this maintenance.

Snow Removal

At the end of construction on 1 December, the compacted surface on the 10-70 area was depressed 1.3 feet below the natural surface. Between 7 and 11 December, a blizzard completely inundated the 150-foot-wide by 6,000-foot-long area with drift. Its depth ranged from 0.8 to 1.3 feet; volume was about 33,000 cubic yards and weight estimated at 14,000 tons.

Clearing the drift was delayed until 15 December to assist ASA in clearing the storm drift from the ice runway at Williams Field. During this delay, there was a marked increase in hardness in the drift snow on the 10-70 area.

Working 10 hours a day between 15 and 18 December, two snowplow carriers were used for 41 machine-hours and a snowplane, serving as a grader, was used for 19 machine-hours to clear the 33,000 cubic yards of drift. On 19 December, the area was leveled and finished with the snowplane and a smoothing drag. A power wagon[16] towed the finishing drag; size 2 snow tractors towed the other equipment.

During the first 18 working hours, only the two snowplows were used for clearing. As the casting distance of the plows was 75 to 90 feet, depending on the velocity and direction of the wind, the first pass was made down the center of the area; subsequent passes progressed outward toward each edge. In four coverages (20 round trips), about 80% of the drift was removed in the middle 50 feet, but less than 65% in the outer 50-foot strips. Four additional round trips were made to remove another 15% of the drift in these two strips.

During the next 20 working hours, a snowplane and a snowplow were used together to remove the remaining drift. The snowplane, working as a grader, windrowed the drift and the snowplow cast off the windrows. Three round trips with the snowplane were required to produce a suitable windrow for casting, but this procedure avoided damaging the compacted surface with the feeder blades on the snowplow carrier. Fifteen round trips with the snowplane and five with the snowplow were necessary to remove the remaining drift. One to 2 inches of drift were left on the compacted snow for leveling and finishing the surface.

The rate of removal was 805 cubic yards or 346 tons per hour, based on the 41 snowplow-hours required to remove all the drift; however, the total machine time for clearing, including windrowing with the snowplane, was 60 hours. With this time used as a basis, the clearing rate was 550 cubic yards, or 233 tons per hour. This clearing rate was about one-fourth of the 2,000-cubic-yards-per-hour rate established with the snowplow carriers in the fresh drift at Williams Field, and over one and one-half times the 342-cubic-yards-per-hour rate established with the size 6 snow tractors working as bulldozers.[7]

Clearing the 5-day-old drift from the 10-70 area presented several problems not encountered in the fresh drift on the sea ice runway at Williams Field. Age-hardening made it difficult to distinguish the drift from the compacted snow by machine alone. Frequent probing was necessary after 60% of the drift was removed to determine the safe cutting depth for the snowplow carriers. The concave profile of the drift across the 10-70 area was misleading, and using this profile as a plane of reference resulted in extra work to remove the drift along the outside edges of the area. On the ice runway, both a change in color and a harder surface were available for reference when removing the drift.

Drift on compacted snow should be removed as soon as possible to simplify recognition between the drift and the compacted surface. When compacted snow is completely inundated with a foot or more of drift, stakes at frequent intervals should be used on the area to provide a uniform plane of reference during removal.

In previous studies on drifting snow,[19] it was found that drift accumulation on a depressed area in a natural snowfield is dependent upon the difference in elevation between the depressed area and the adjacent surface. As the 10-70 area was depressed 1.3 feet below the natural surface during construction, some drifting was anticipated during the summer season. Formation of spoil banks up to 3.1 feet high along the sides of this area when clearing the drift from the 7-11 December storm further increased its susceptibility to drift.

After the 7-11 December snow drift was cleared from the 10-70 area on 18 December, frequent light drifting in moderate winds resulted in new drift over most of the area by 24 December. This, coupled with the light drift cover remaining after the clearing, resulted in a 2- to 6-inch-deep cover of drift on the 10-70 area for the 24 December aircraft test. Following this test, it was decided to remove all this drift to observe the action of the wheels on the test aircraft on compacted snow. Before this could be done, moderate winds between 25 and 28 December deposited 2 to 3 feet of new drift over a 30-foot-wide strip along the south side of the area.

Visibility and the direction and velocity of the wind controlled the removal of this drift; it was accomplished intermittently between 29 December and 2 January. An estimated 5,000 cubic yards of shallow drift over most of the area was removed by windrowing with the snowplane and casting with the snowplow carriers. Size 2 snow tractors were used to tow the snowplows, but the rubber-tired truck-tractor,[10] introduced in the DF-65 trials for towing the maintenance equipment, was used to tow the snowplane. With the truck-tractor serving as a tow vehicle, windrowing with the snowplane was accomplished at 8 mph compared with 2 mph when towing it with a tractor.

The 13,000 cubic yards of drift in the 30-foot-wide strip along the south side were removed entirely with the snowplow carriers. The drift was fresh and easily distinguished from the compacted snow surface. After this strip of drift was removed, a 25-foot-wide section of the south spoil bank (Figure 4) was removed to form a catch basin along this side of the area. The bottom of the basin was level with the surface of the compacted snow. About 17,000 cubic yards of snow were removed to form this basin.

Between 2 and 19 January, intermittent winds gradually filled the catch basin with a wedge of drift snow. It was level with the top of the spoil bank along the south side of the basin and tapered out at the edge of the 10-70 area. Following this, moderate winds on 20 January deposited about 4 inches of drift over a 20-foot-wide strip of the area next to the basin. On 21 January, this 1,500 cubic yards of drift was moved into the catch basin with the snowplane used as a grader. On this job it was towed at speeds up to 25 mph with the truck-tractor.

During the summer season of DF-65, about 70,000 cubic yards of snow were removed from the depressed 150-foot-wide by 6,000-foot-long 10-70 area to keep it open for aircraft traffic. By comparison, in DF-62, a 200- by 4,000-foot-wide area of compacted snow was elevated 0.7 foot above the natural surface in January 1962. During the next 8 months, February to October 1962, this area accumulated only 9,000 cubic yards of drift, or about one-eighth of the amount removed from the 10-70 area.

Surface Finishing

The 10-70 area was resurfaced with the finishing drag each time drift was removed from the area and before each aircraft test. The finishing drag always produced a fairly smooth finish, but it was most effective when the surface temperature of the snow was at or near 32°F. At this temperature snow was slightly moist and the drag produced a hard slick finish. Initially, during the DF-65 trials, the finishing drag was towed with the power wagon;[18] later, with the truck-tractor.[10] Use of these two rubber-tired vehicles made finishing possible at speeds up to 25 mph, compared with speeds of 2 to 5 mph when the finishing drag was towed with a size 2 snow tractor. With the truck-tractor as tow vehicle, 2 hours were required to cover the 150- by 6,000-foot area. This coverage was much faster than that possible with a tractor, and the rubber tires on the truck-tractor did not damage the compacted snow surface.

REPAIRS

The 10-70 area was tested six times with LC-130F aircraft on wheels between 6 December and 14 February. Punching failures directly under the main wheels of the aircraft occurred from place to place in the DF-65 compacted-snow layer in all but the 14 February test. These breakthroughs, which did not penetrate the DF-64 layer, were caused by two types of processing misses in the DF-65 layer which resulted in zones of low-strength snow. Repairs to the area were made after each aircraft test. They included not only the low-strength snow detected by the aircraft wheels, but also other low-strength snow found by probing with the Rammsonde.

Processing Misses

One type of low-strength snow in the DF-65 layer was caused by partial-processing misses between mixer lanes down the middle of the area (Figure 6). These misses resulted from sideslip of the snow mixers during construction; they were narrow and intermittent.

As described under Construction of the DF-65 Layer, each mixer lane was processed four times. Beginning on 12 November, the first pass of each new lane abutted the previous lane and the last three passes were offset to overlap the previous lane about 2 feet. To compensate for the tendency of the mixers to sideslip into the freshly processed snow, the tractor operators were constantly realigning the mixer trains to obtain the desired overlap. Until they became skilled in this, overcorrection frequently moved the mixers back and forth across the prescribed line of travel. This resulted in numerous narrow strips between the mixer lanes being processed with only one or two mixer passes.

Examination showed that these between-mixer-lane partially processed strips varied from a few inches up to 3 feet wide, and from a few feet up to several hundred feet long. In some instances, their occurrence was so frequent that they appeared to be continuous for almost the full length of the area. Age-hardening produced some strength in these strips, thus preventing early detection with the snow test instruments. When the strength of the snow became dependent upon its temperature, there was a marked difference in strength between the snow in the between-mixer-lane strips and the completely processed snow in the mixer lanes.

The other type of low-strength snow in the DF-65 layer was caused by seams of unprocessed snow between the DF-64 and DF-65 layers (Figure 6). These misses were caused by varying the cutting depth of the snow mixer rotors during construction; they were slightly crowned in cross section and varied in size and shape.

As discussed under Construction of the DF-65 Layer, the snow cover down the middle of the area varied as much as 6 inches from place to place. To avoid stalling the mixer engines during processing, the depth of the rotor cut was varied as much as 4 inches, depending on the thickness of the snow cover. After processing, eight pronounced undulations up to 6 inches high were removed to level the surface of the DF-65 layer; they varied from 10 to 50 feet in width and from 50 to 700 feet in length. Examination showed that seams of unprocessed snow up to 4 inches thick existed under these pronounced undulations and, after leveling, the processed snow over these seams was only 6 inches thick in places (Figure 7). Some of the seams were found when testing the area with the snow test instruments. None were repaired until they failed during the aircraft tests, thus permitting observations on the bearing capacity of the compacted snow over the seams.

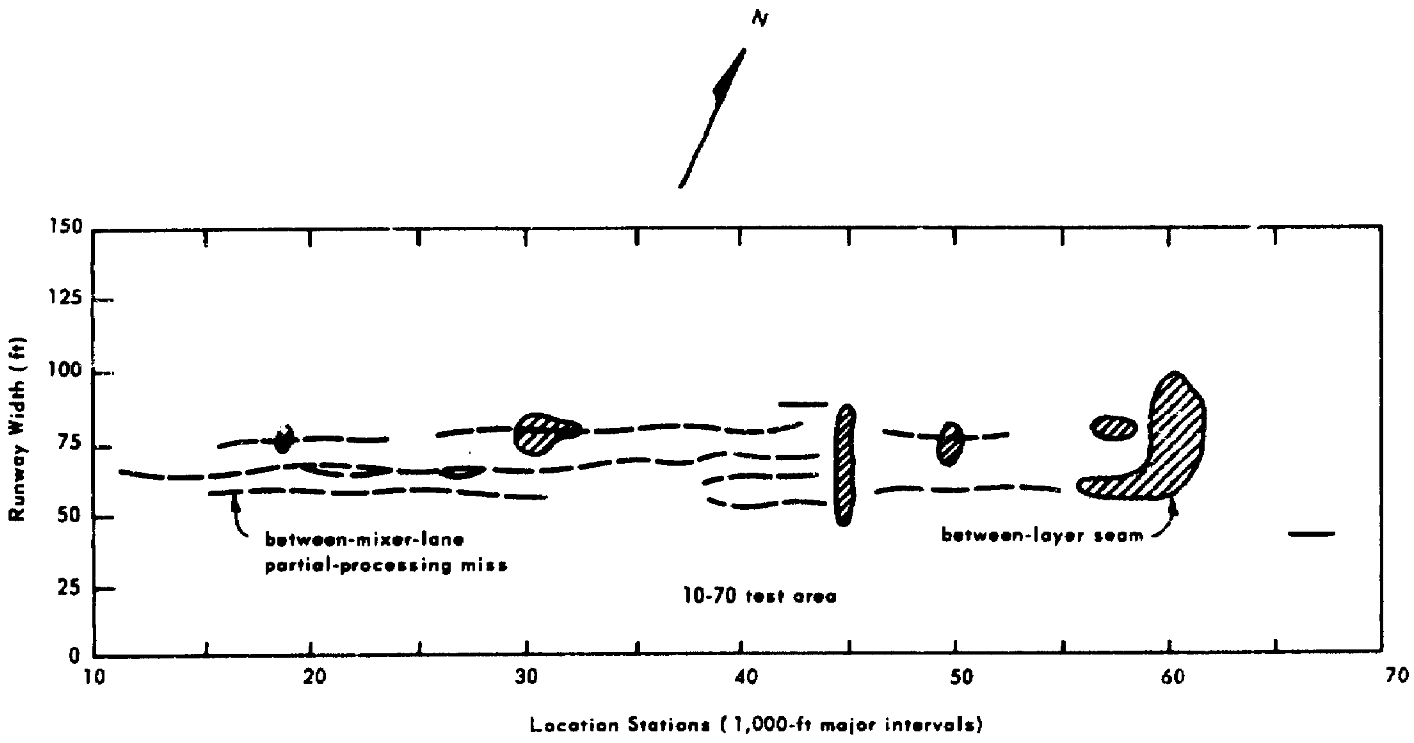


Figure 6. Location of processing misses in the DF-65 compacted-snow layer.

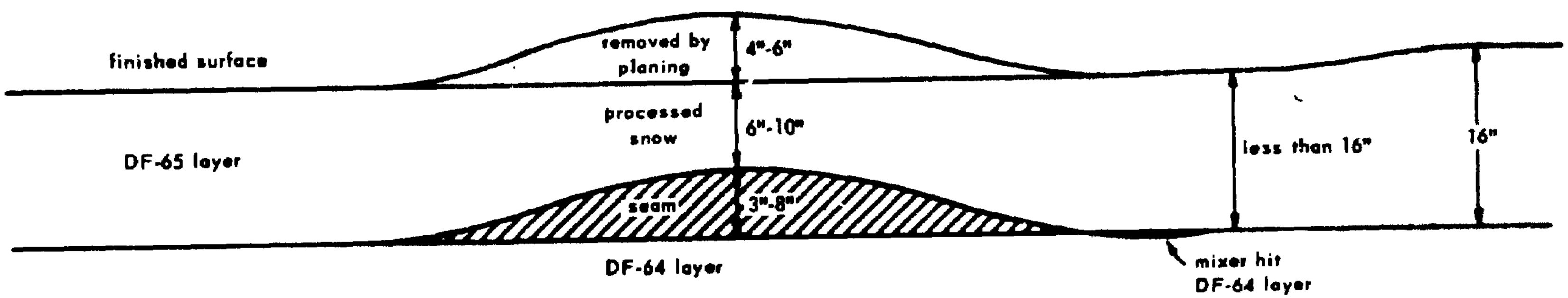


Figure 7. Cross section showing seam of unprocessed snow between the DF-64 and DF-65 layers of compacted snow.

Water Patch

During the 6 December LC-130F aircraft test, a between-mixer-lane partial-processing miss near Station 45+00 was detected by the main wheels of the aircraft during a turn. By Rammsonde probing, it was found that the miss was 50 feet long, up to 2 feet wide, and parallel with the edge of the area. This partial-processing miss was repaired with fresh water on 20 December following removal of the drift snow that accumulated in the 7-11 December storm.

To make the water patch, 175 gallons of fresh water was added to the surface of the miss with a small hose and spaded in to form a slurry (Figure 8). The temperature of the water was 40°F and the temperature of the snow was 20°F. After addition of the water, the patch was compacted with the 20-psi high-flotation tires on the truck-tractor. Then a slurry of new snow and water was added to bring the level of the patch up even with the surface of the test area.

Figure 8. Making a water patch during DF-65 trials.

Four days later there was a marked increase of strength in the patch, but a complete absence of ice lenses in the patched layer of snow. Examination showed that much of the water had filtered completely through the DF-65 layer and 10 inches into the DF-64 layer to form a 1/2- to 1-inch-thick layer of ice 26 inches below the surface.

Snow Mixer Patches

During the 24 December LC-130F aircraft test, a between-mixer-lane partial-processing miss near Station 35+00 and three between-layer seams of unprocessed snow near Stations 30+00, 45+00, and 50+00 were detected by the main wheels of the aircraft. By Rammsonde probing, it was found that the partial-processing miss near Station 35+00 was 320 feet long and up to 2 feet wide. It was 70 feet from the south edge of the area and parallel with this edge (Figure 9). The between-layer seam of unprocessed snow near Station 30+00 was 330 feet long and 17 feet wide. The one at Station 45+00 was 100 feet long and 48 feet wide, and that at Station 50+00 was 100 feet long and 18 feet wide. All were located along the middle of the area, and the unprocessed seam of snow in all three was up to 4 inches thick.

The 24 December failures were repaired between 26 and 29 December with snow mixer patches using three-pass processing and the model 36/42 snow mixer fitted with the 36-inch-diameter rotor. To increase the percentage of fine snow particles in the patches and to avoid depressing these below the surface, a 3-inch layer of old natural snow from the south spoil bank was placed over each area before it was processed with the snow mixer. The first mixer pass was made in first gear at a rotor peripheral speed of 1,682 fpm, the second pass in second gear at a rotor peripheral speed of 4,756 fpm, and the third pass in fourth gear at the rotor peripheral speed of 5,937 fpm. The cutting depth of the rotor was set at 18 inches and the travel speed of the mixer train adjusted to maintain this cutting depth and the rotor peripheral speed selected for each pass. Each pass was made over the entire area being patched before proceeding with the next pass. At the start of each mixer lane, the rotor was positioned over the edge of the patch and forced down to its full cutting depth before the mixer train was moved forward. The mixer was stopped at the end of the patch and the rotor pulled straight up. Where more than one 8-foot-wide mixer lane was required for a patch, each new lane overlapped the preceding lane about 3 feet. Immediately after the third mixer pass, the patch was graded with the snow-plane and then rolled three times with the snow-compaction roller.

Two days after processing, the patches were rolled 10 times with the 9-ton, 13-wheel, pneumatic-tired roller to increase their surface hardness. The 19,000-pound rubber-tired truck-tractor (Figure 10) was used to tow the roller instead of the size 2 snow tractor as during compaction. This permitted rolling at speeds of 10 to 15 mph compared with speeds of 2 to 3 mph with the tractor.

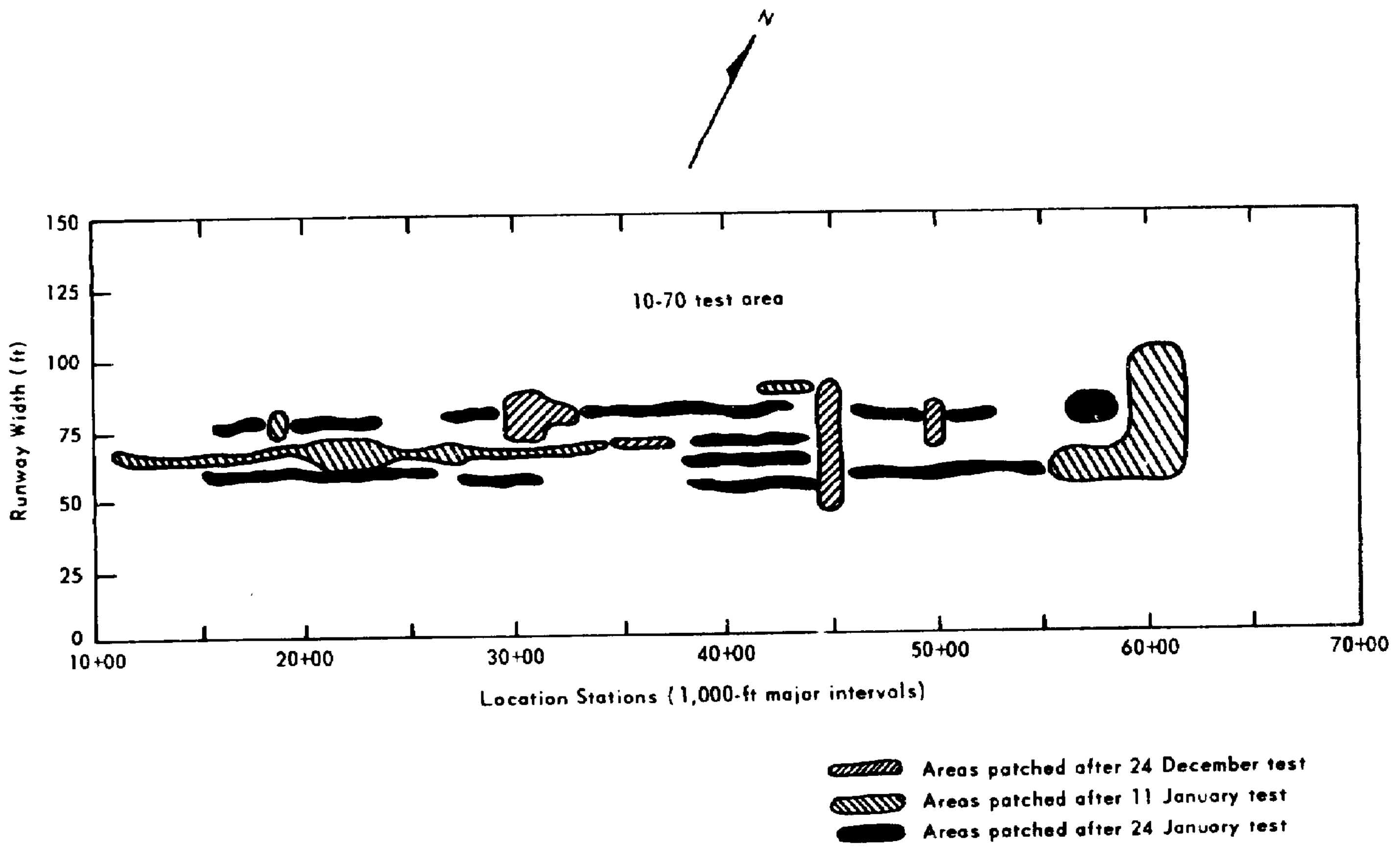


Figure 9. Location of areas patched with snow mixer following LC-130F aircraft tests to 24 January 1965.

Figure 10. Truck-tractor towing the 9-ton, 13-wheel pneumatic-tired roller used for surface-hardening in the DF-65 trials.

During the 11 January LC-130F aircraft test, three additional between-mixer-lane partial-processing misses and two between-layer seams of unprocessed snow were detected by the main wheels of the aircraft. By probing with the Rammsonde, it was found that one of the partial-processing misses was almost 2,500 feet long, ignoring short discontinuities from place to place. It started near Station 10+00 and ended near Station 35+00. The average width of this miss varied from 1 to 2 feet except between Stations 20+00 and 25+00, where it was over 8 feet wide in places. The other two between-lane misses were located near Stations 45+00 and 65+00. They were both less than 100 feet long and less than 2 feet wide. A small between-layer seam of unprocessed snow was found near Station 20+00 and a very large one near Station 60+00. Both were located along the middle of the area; the maximum thickness of the unprocessed snow in these seams was also 4 inches deep. These five areas were repaired with snow mixer patches between 13 and 16 January using the technique described previously, including the addition of a 3-inch layer of old natural snow before processing.

During the 24 January aircraft test, four new between-mixer-lane partial-processing misses and one between-layer seam of unprocessed snow were detected by the main wheels of the aircraft. By probing with the Rammsonde, it was found that two parallel between-mixer-lane misses extended intermittently between Stations 15+00 and 55+00. One was located about 55 and the other about 80 feet from the south side of the area. In addition, two other parallel between-mixer-lane misses about 8 feet apart were found near the middle of the area between Stations 38+00 and 44+00. All these misses were less than 2 feet wide. The between-layer seam of unprocessed snow was found near Station 58+00. It was in the middle of the area, and had a maximum depth of only 3 inches.

These five areas were repaired with snow mixer patches between 26 and 30 January. The repairs were similar to those previously described except, for lack of haul equipment, the 3-inch layer of old natural snow was omitted in these patches. This omission resulted in 3-foot-wide by 6- to 10-inch-deep concave depressions in the surface where the mixer entered and left the area being patched. These depressions were filled with processed snow on 31 January from a 100-foot-long strip of processed snow manufactured alongside the 10-70 area. The freshly processed snow was hauled to the patch by truck and shoveled and tamped into place by hand. It was then compacted with five passes of the snow-compaction roller towed with a size 2 snow tractor.

On 1 February, these patches were rolled with the 9-ton, 13-wheel, pneumatic-tired roller. Rolling was discontinued after five passes as roller wheels were sinking 3 to 4 inches into the surface. Rolling was resumed on the following day, but it was again discontinued after five passes as the roller wheels were sinking 4 to 6 inches. On 4 February, the patches were smoothed off with the model 80 snowplane and the finishing drag, and between 10 and 12 February an attempt was made to increase the bearing capacity of these patches by rolling them once a day with the pneumatic-tired roller and smoothing them with the finishing drag. The truck-tractor was used to tow this equipment.

PART III. PHYSICAL PROPERTIES OF THE SNOW

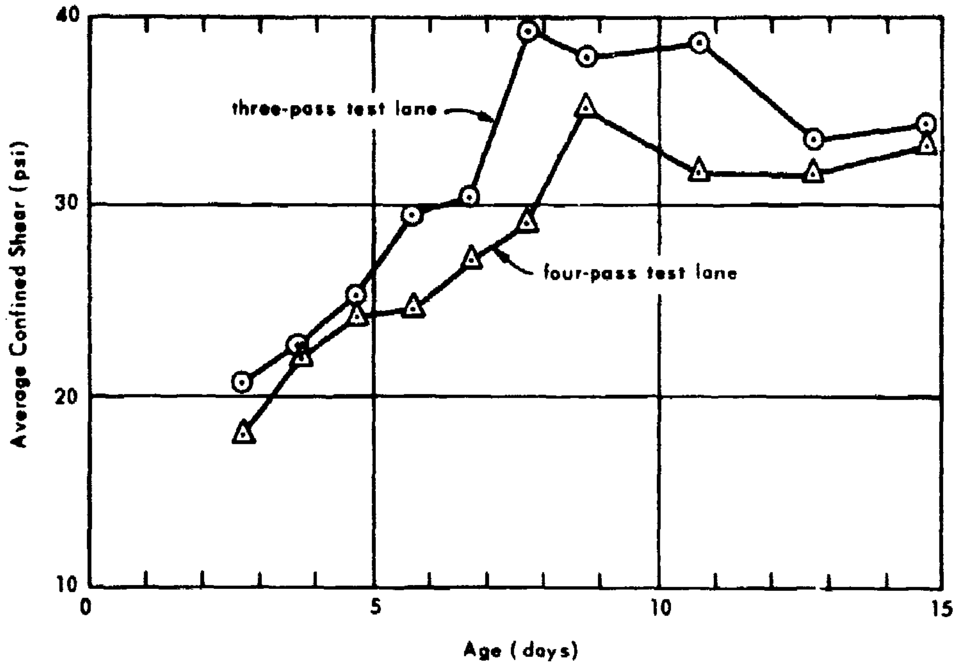
Strength, density, and other physical properties of the snow were measured before, during, and after compaction. Strength measurements were made with the NCEL-type confined-shear test apparatus. As discussed under Test Procedures in Part I, the load-carrying capacity in pounds per square inch of snow surface area for the DF-65 Trials was accepted as one-fourth of the resistance to confined shear. The Rammsonde was used very little for strength measurements in these trials; it was used extensively to probe the area for zones of low-strength snow during the aircraft tests.

TEST LANES

Before constructing the DF-65 layer, two test lanes were made on 7 November in natural snow near the 10-70 area. Both lanes were one mixer wide. One was made with three mixer passes and the other with four. After mixing, the processed snow in both lanes was 16 inches thick; it was not compacted with a tractor or a roller.

Age-hardening was observed in these lanes for 15 days following processing. Changes in average strength as measured by confined shear and the maximum, minimum, and daily average air temperature and the snow temperature 6 inches below the surface during this period are shown in Figure 11. During the first 7 days of age-hardening, the growth of strength was fairly uniform in both lanes, with a slightly faster growth rate in the three-pass lane. The strength of the processed snow reached a maximum after 7 days of age-hardening in the three-pass lane; it reached a maximum after 8 days in the four-pass lane. After 15 days, there was less than 2% difference in the average confined shear strength in the two lanes, 34.1 psi in the three-pass lane, and 33.5 psi in the four-pass lane. At that time, the average confined strength and Rammsonde hardness index for 4-inch increments in these two lanes were:

Depth (in.)	Three-Pass Lane		Four-Pass Lane	
	Average Confined-Shear Values (psi)	Average Ramm Hardness Index (R)	Average Confined-Shear Values (psi)	Average Ramm Hardness Index (R)
0-4	38.5	430	26.6	400
4-8	33.7	520	37.3	450
8-12	33.5	460	35.0	460
12-16	30.6	420	35.0	420
Average	34.1	460	33.5	430



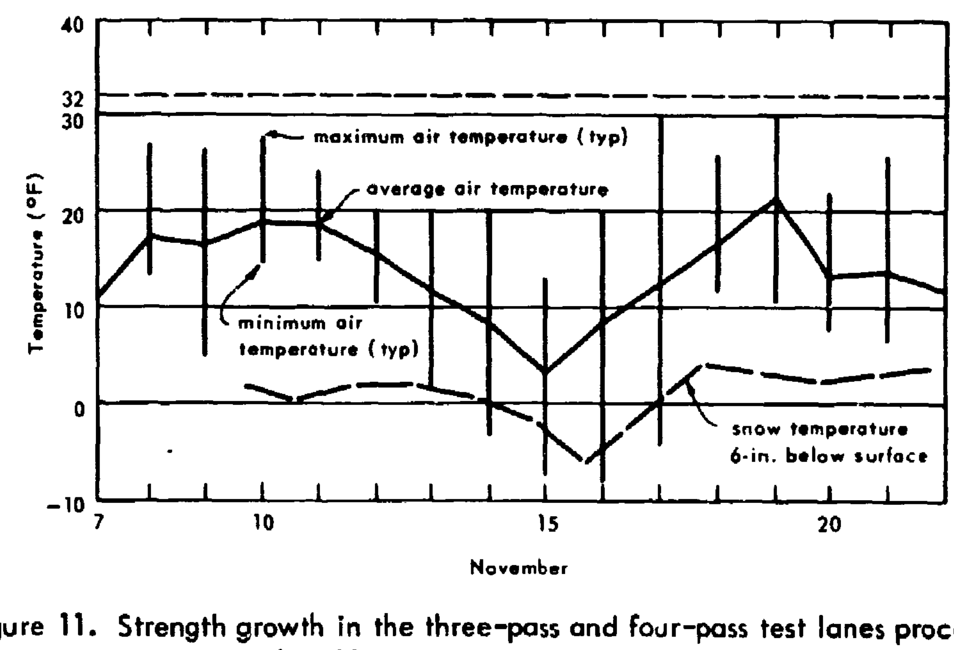


Figure 11. Strength growth in the three-pass and four-pass test lanes processed on 7 November 1964.

This data shows that the strength of the processed snow was fairly close and uniform in both test lanes. It indicated that three-pass processing with the model 36/42 mixers was as effective as four-pass processing in the natural snow on the Ross Ice Shelf near McMurdo Station.

GROWTH OF STRENGTH IN THE DF-65 LAYER

The growth of strength during age-hardening was observed on three 6,000-foot-long strips of snow compacted on different days in the DF-65 layer on the 10-70 area. This layer was processed with four mixer passes and rolled five times with the snow-compaction roller. Then, 3 to 8 days later, it was rolled 10 times with the 9-ton, 13-wheel, pneumatic-tired roller.

Changes in average strength as measured by confined shear in these three strips and the maximum, minimum, and daily average air temperature during age-hardening are shown in Figure 12. Each strength measurement there is the average of three or more cores at three different locations on the strips. The sampling points on each strip were changed for each set of tests.

11/10 Strip

The first strip selected for observation was 16 feet wide. It was located along the south side of the 10-70 area. Designated as the 11/10 strip, this was compacted on 10 November and rolled with the 9-ton roller on 13 November.

The average confined-shear strength in the 11/10 strip increased rapidly to 48.2 psi during the first 6 days after processing (Figure 12), with the greatest increase in the top 4 inches of the compacted snow. The average strength in this 4 inches reached 64.9 psi compared with an average of 42.7 psi in the bottom 12 inches. The average air temperature during this period was 13°F, the maximum 24°F, and the minimum -9°F.

During the next 6 days, the average confined-shear strength in the 11/10 strip dropped 15% to 40.9 psi, with the greatest loss of strength in the top 4 inches. This 4 inches lost 31% of its strength (64.9 to 42.3 psi) compared with a loss of 6% to 40.1 psi in the bottom 12 inches. The average air temperature during this period was 17°F, the maximum 32°F, and the minimum -4°F.

During the next 10 days, the average confined-shear strength in the 11/10 strip increased gradually to 45.6 psi, for a gain of 11%. The average strength in the top 4 inches increased 13% to 49.7 psi, and the bottom 12 inches increased 10% to 44.2 psi. The average air temperature during this period was 17°F, the maximum 40°F, and the minimum -1°F.

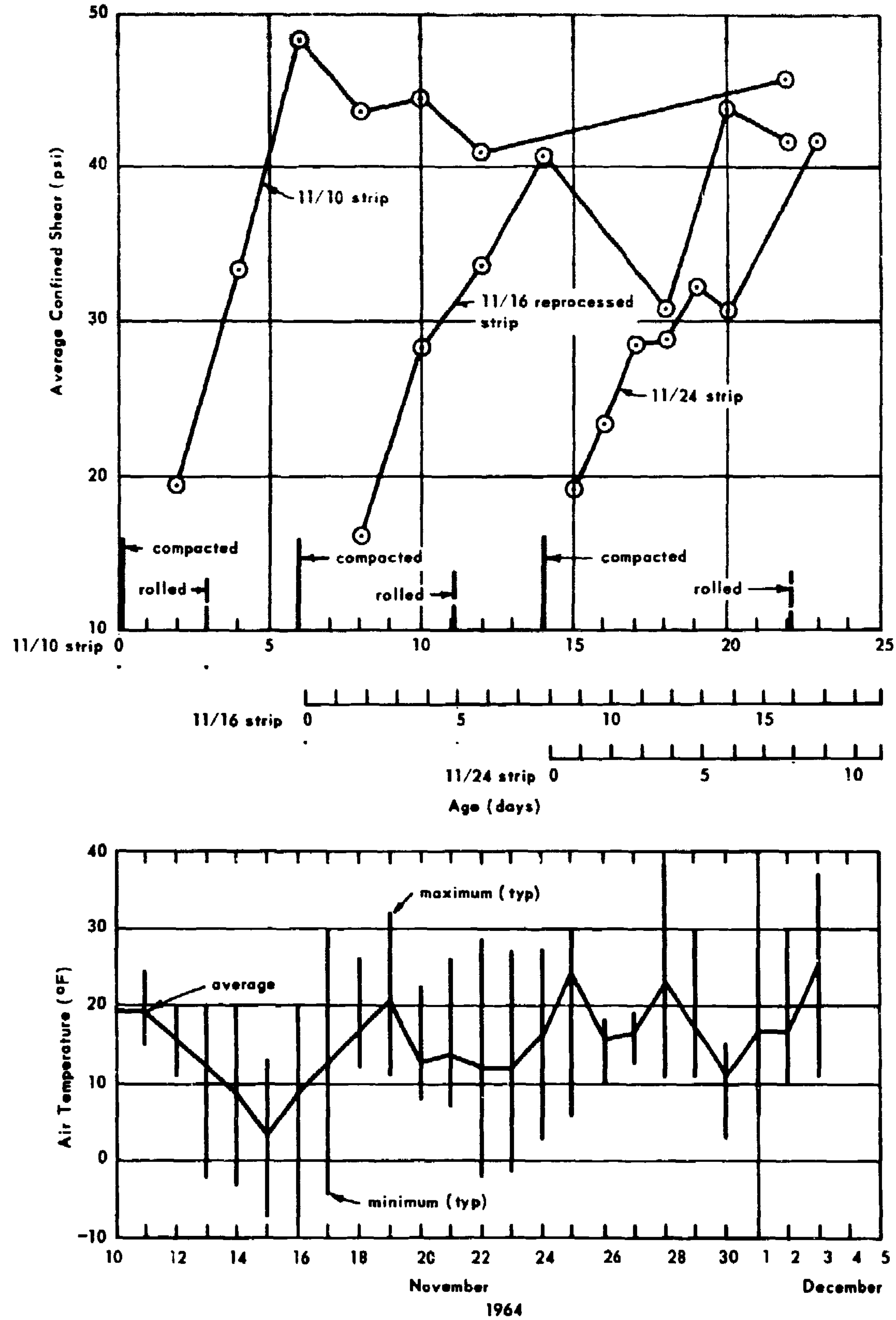


Figure 12. Strength growth during age-hardening in three strips of compacted snow in the DF-65 layer on the 10-70 test area.

11/16 **Reprocessed Strip**

The second strip selected for observation was 20 feet wide. It was the reprocessed strip (see Construction of the DF-65 Layer, Part II) located adjacent to the 11/10 strip. Designated as the 11/16 strip, this was reprocessed on 16 November and rolled with the 9-ton roller on 21 November.

The average growth of confined-shear strength in the 11/16 reprocessed strip was comparable to that of the 11/10 strip (Figure 12) during the first 8 days of age-hardening even though the snow was coarse and granular and contained a high percentage of bonded chunks greater than 2 inches in size when reprocessed. After 8 days, the average strength in the reprocessed strip was 40.7 psi. The greatest increase was in the top 4 inches of the compacted snow which reached an average strength of 55.5 psi compared with 42.7 psi in the middle 8 inches and 21.7 psi in the bottom 4 inches. The average air temperature during this period was 14°F, the maximum 32°F, and the minimum -4°F.

During the next 4 days, the average confined-shear strength in the 11/16 reprocessed strip dropped 25% to 30.5 psi, with the greatest loss of strength in the top 4 inches. This 4 inches lost 46% of its strength (55.5 to 29.7 psi) compared with a loss of 13% to 37.3 psi in the middle 8 inches and a loss of 18% to 17.7 psi in the bottom 4 inches. The average air temperature during this period was 19°F, the maximum 40°F, and the minimum 6°F.

During the next 4 days, the average confined-shear strength in the 11/16 reprocessed strip increased 37% to 41.7 psi, with the greatest increase in the top 4 inches. This 4 inches increased to 50.1 psi compared to an increase of 23% (37.3 to 46.0 psi) in the middle 8 inches and 39% (17.7 to 24.6 psi) in the bottom 4 inches. The average air temperature during this period was 18°F, the maximum 37°F, and the minimum 3°F.

11/24 Strip

The third strip selected for observation was 17 feet wide. It was located along the north side of the area. Designated as the 11/24 strip, this was processed on 24 November and rolled with the 9-ton roller on 2 December.

The average confined-shear strength in the 11/24 strip increased rapidly to 28.5 psi during the first 3 days after processing (Figure 12), with the greatest increase in the bottom 12 inches of the compacted snow. The average strength in the bottom 12 inches reached 31.6 psi compared with 19.1 psi in the top 4 inches. The average air temperature during this period was 18°F, the maximum 30°F, and the minimum 6°F.

During the next 3 days, the average confined-shear strength in the 11/24 strip increased only 5% to 30.4 psi, with all of the increase in the top 4 inches. This 4 inches increased 41% to 27.0 psi compared with a slight loss (31.6 to 31.4 psi) in the bottom 12 inches. During this period, the average air temperature was 18°F, the maximum 40°F, and the minimum 3°F.

In the next 3 days, during which time the 11/24 strip was rolled 10 times with the wobble-wheeled roller, the average confined-shear strength increased 37% to 41.5 psi, with the greatest increase in the top 4 inches. This 4 inches increased 39% to 37.6 psi compared to an increase of 26% to 42.8 psi in the bottom 12 inches. During this period, the average air temperature was 18°F, the maximum 37°F, and the minimum 6°F.

Rolling for Surface Hardness

Rolling the DF-65 layer with 10 passes of the 9-ton, 13-wheel, pneumatic-tired roller for increased surface hardness appears to have also favorably influenced the rate and amount of strength growth in the compacted snow during age-hardening. The 11/10 strip was rolled 3 days after being compacted. As shown in Figure 12, its strength increased continuously until it reached a maximum 6 days after compaction. The 11/16 reprocessed strip was rolled 5 days after being compacted. As shown in Figure 12, there was a slight decline in the growth of strength in this strip between the fourth and sixth day but, after rolling, the rate of strength growth increased until it reached a maximum 8 days after compaction.

The 11/24 strip was rolled 8 days after being compacted. As shown in Figure 12, 3 days after compaction the growth of strength in this strip declined sharply and, during the next 3 days, its rate of growth was very slow. After rolling, the rate of strength growth increased rapidly, and 9 days after compaction its strength approached that of the maximum strength achieved in the other two strips during age-hardening.

DENSITY

Before the DF-65 layer was compacted, the average density in the 22- to 28-inch-thick cover of natural snow on the 10-70 area was 0.36 gm/cm^3. After compaction, the density for each 4-inch increment of snow in the DF-65 layer was obtained in the four-pass once-processed snow that covered most of the area, the four-pass reprocessed snow in the 11/16 reprocessed strip, and in the mixer patch at Station 45+00 that was made by adding 15% of new snow to the patch and processing this snow and the once-processed snow in the patch with three mixer passes. These densities were observed after the strip and the patch were rolled with the 9-ton pneumatic-tired roller. They were:

Depth (in.)	Density (gm/cm^3)		
	Once-Processed Snow	Reprocessed Snow	Mixer Patch
0-4	0.58	0.59	0.61
4-8	0.57	0.60	0.60
8-12	0.56	0.58	0.59
12-16	0.53	0.52	0.60
Average	0.56	0.57	0.60

The average density of the snow cover on the 10-70 area was increased about 55% with the four-pass processing technique used to compact the DF-65 layer. Reprocessing with the same technique increased the average density of this snow only 0.01 gm/cm^3, but it did raise the density in the top 8 inches to almost 0.60 gm/cm^3. Reprocessing with 15% of new snow by volume and three mixer passes at travel speeds that permitted maximum rotor peripheral speeds achieved a nearly uniform density of 0.60 gm/cm^3 throughout the compacted layer.

LOAD-CARRYING CAPACITY IN THE DF-65 LAYER

On 2 December 1964, confined-shear tests were made at random locations over the whole 10-70 area to determine the maximum, minimum, and average load-carrying capacity for the DF-65 layer. The age of the layer was established as 8 days at the time of these tests even though the compacted snow in the layer ranged from 8 to 22 days old. Throughout the remainder of the summer season, similar random sample tests were made at 4- to 22-day intervals on the DF-65 layer. The results of these tests, which were concluded on 14 February 1965, along with the average monthly temperature and the total monthly solar radiation at the test site during the test period, are shown in Figure 13.

On 2 December the maximum load-carrying capacity of the 8-day-old DF-65 layer as determined by 22 confined-shear tests was 235 psi, the minimum 112 psi, and the average 162 psi. By 16 December the maximum load-carrying capacity was 255 psi for an increase of 9%, the minimum 117 psi for an increase of 4%, and the average 184 psi for an increase of 14%. Between 16 December and 6 January, which covers the period of maximum solar radiation at the test site (Figure 13), the maximum load-carrying capacity decreased to 160 psi or 37%, the minimum to 104 psi or 11%, and the average to 124 psi or 33%. Between mid-January and mid-February the solar radiation and average air temperature decreased rapidly at the test site. By 12 February the maximum load-carrying capacity of the DF-65 layer was 237 psi for an increase of 48% since early January, the minimum 214 psi for an increase of 106%, and the average 226 psi for an increase of 82%. During the next 2 days, 12 to 14 February, there was a sharp rise in the strength of the DF-65 layer. The maximum load-carrying capacity increased 45% to 332 psi, the minimum 21% to 258 psi, and the average 22% to 276 psi.

Up to 24 December the difference between the maximum and minimum load-carrying capacities in the DF-65 layer was over 125%; by 6 January it was less than 60%, and by 14 February it was less than 30%. This decrease was attributed primarily to the repairs which eliminated most of the zones of low-strength snow in the DF-65 layer. These repairs also contributed to the overall increase of strength in this layer.

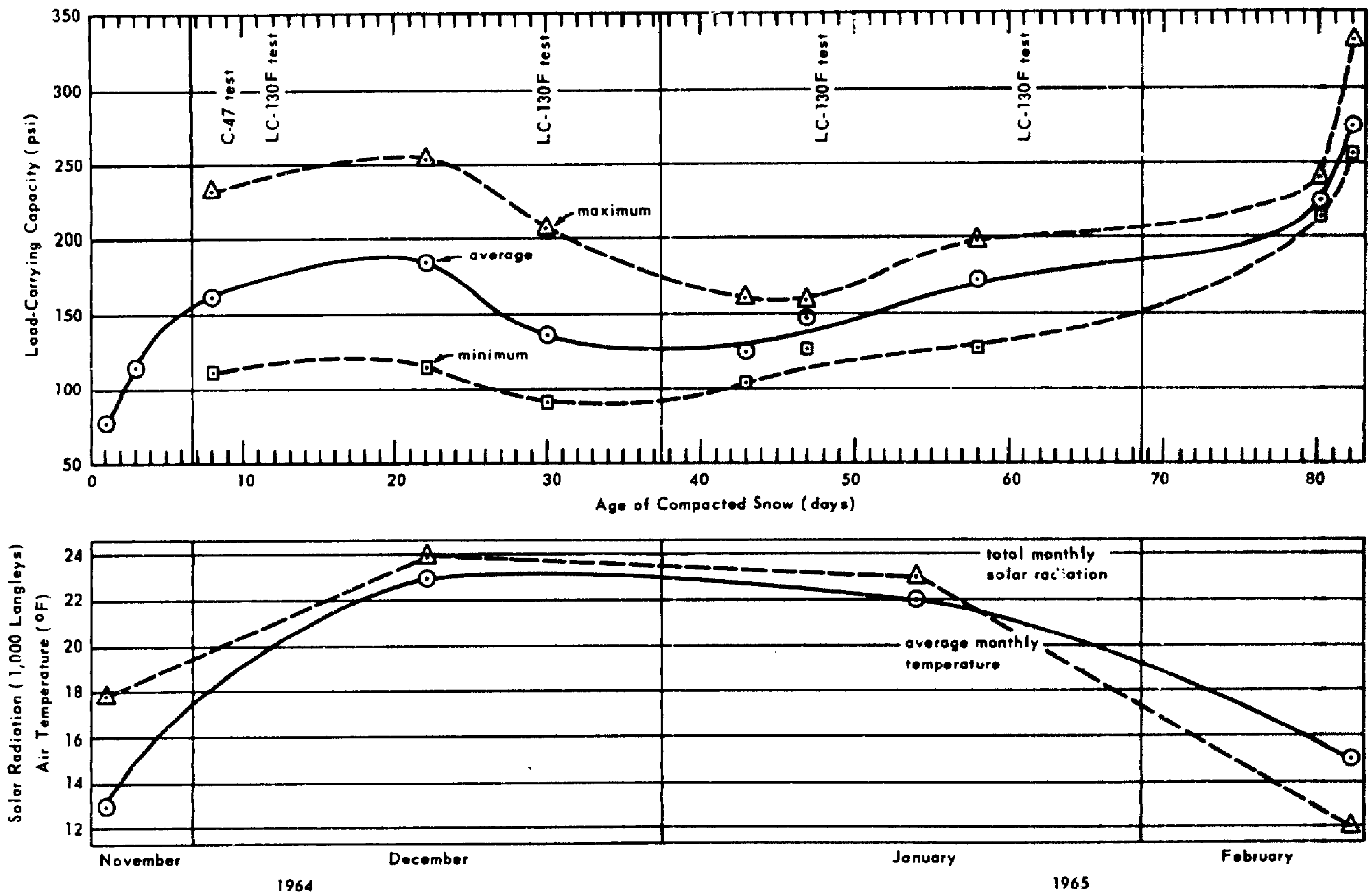


Figure 13. Maximum, minimum, and average load-carrying capacity in the DF-65 compacted-snow layer on the 10-70 test area from December 1964 to February 1965 as determined by confined shear.

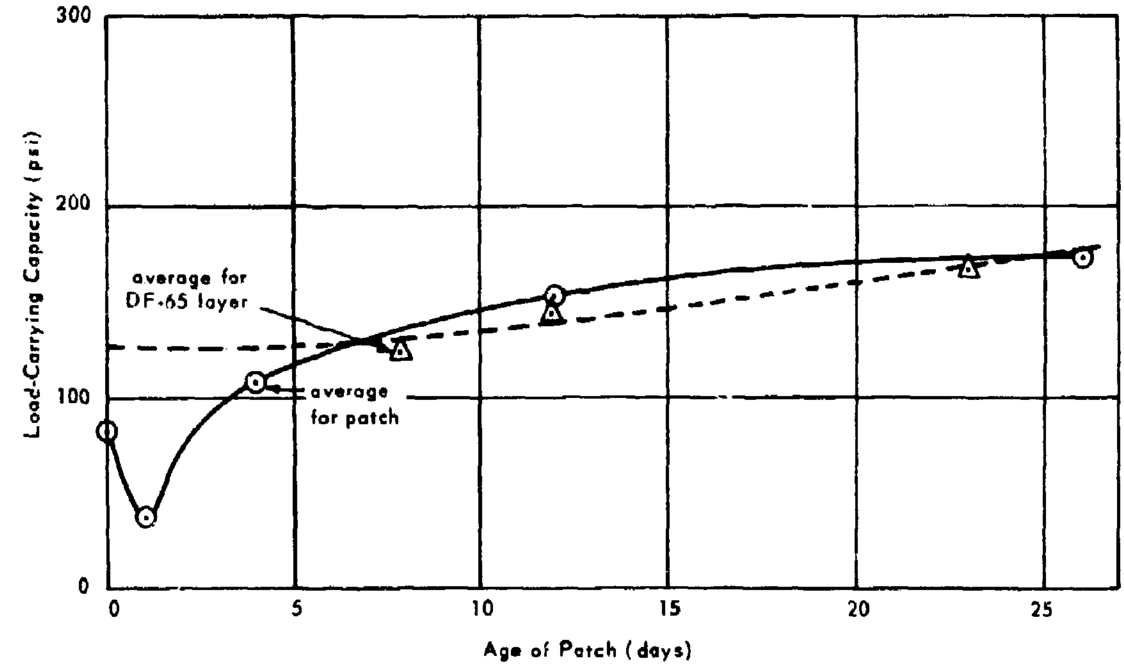
GROWTH OF STRENGTH IN THE SNOW MIXER PATCHES

The growth of strength in the 29 December snow mixer patch at Station 30+00 is shown in Figure 14. The average load-carrying capacity in the 12-inch layer of compacted snow over the 4-inch-thick seam of unprocessed snow at this location was 80 psi before the repair. Fifteen hours after the patch was completed the average load-carrying capacity in the reprocessed snow was 39 psi; 3 days later it was 110 psi or nearly 40% more than before being patched. On 10 January, or 9 days later, it was 159 psi compared with an average load-carrying capacity of 148 psi in the 47-day-old compacted snow in the DF-65 layer. On 24 January, the average load-carrying capacity in the 26-day-old patch was 174 psi, or about the same as the average in the 61-day-old compacted snow. The growth of strength and load-carrying capacity in the other snow mixer patches on the DF-65 layer between late December and mid-January were similar to those at Station 30+00.

The average growth of strength in a 30 January snow mixer patch in the DF-65 layer is shown in Figure 15. The average load-carrying capacity for the zone of low-strength snow at the location of this patch was 70 psi before the repair. Six days later the average load-carrying capacity in the reprocessed snow was 129 psi. The maximum was 151 psi and the minimum 99 psi, representing a difference of about 34%. On 8 February, 9 days after the repair, the average load-carrying capacity in the patch was only 120 psi, or about one-half the average for the 76-day-old compacted snow in the DF-65 layer. In an attempt to increase the bearing capacity of the late January patches, they were rolled once a day with the 9-ton, 13-wheel, pneumatic-tired roller, starting on 10 February. Within 3 days the average load-bearing capacity in the 29 January patch increased nearly 30% to 154 psi, and within 5 days it increased nearly 50% to 178 psi. During this same period, however, the average load-bearing capacity in the 82-day-old compacted snow in the DF-65 layer increased 45% without the rolling.

TEMPERATURE IN THE NATURAL AND COMPACTED SNOW

Using thermopoles, temperatures were observed daily in the natural and compacted snow starting on 28 December. These observations were made at 3-inch intervals to a depth of 3 feet below the surface and at 6-inch intervals from 3 to 5 feet below the surface. Between 0001 hours on 28 December and 1800 hours on 30 December, the snow temperatures were observed at 3-hour intervals. After that they were observed twice a day until the end of the trials.



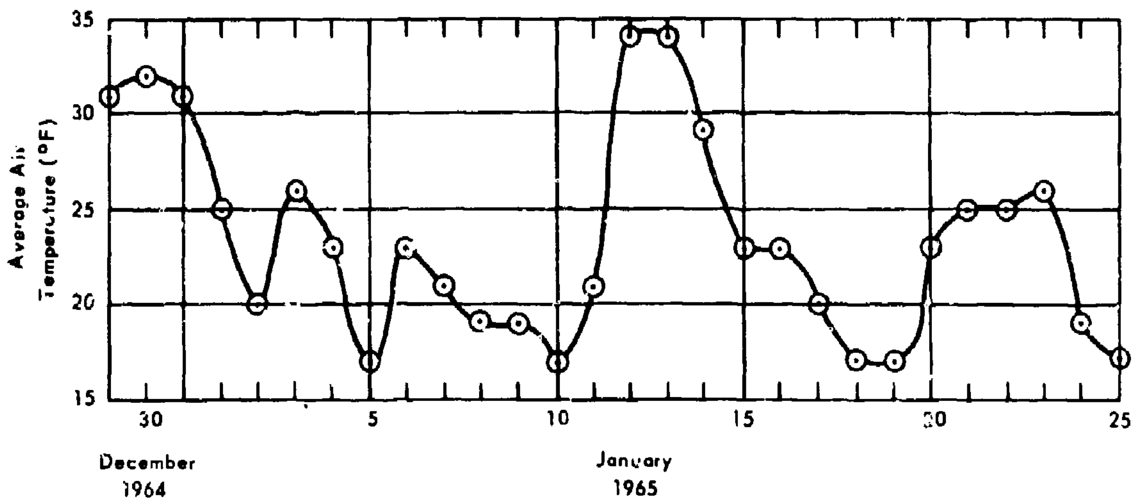
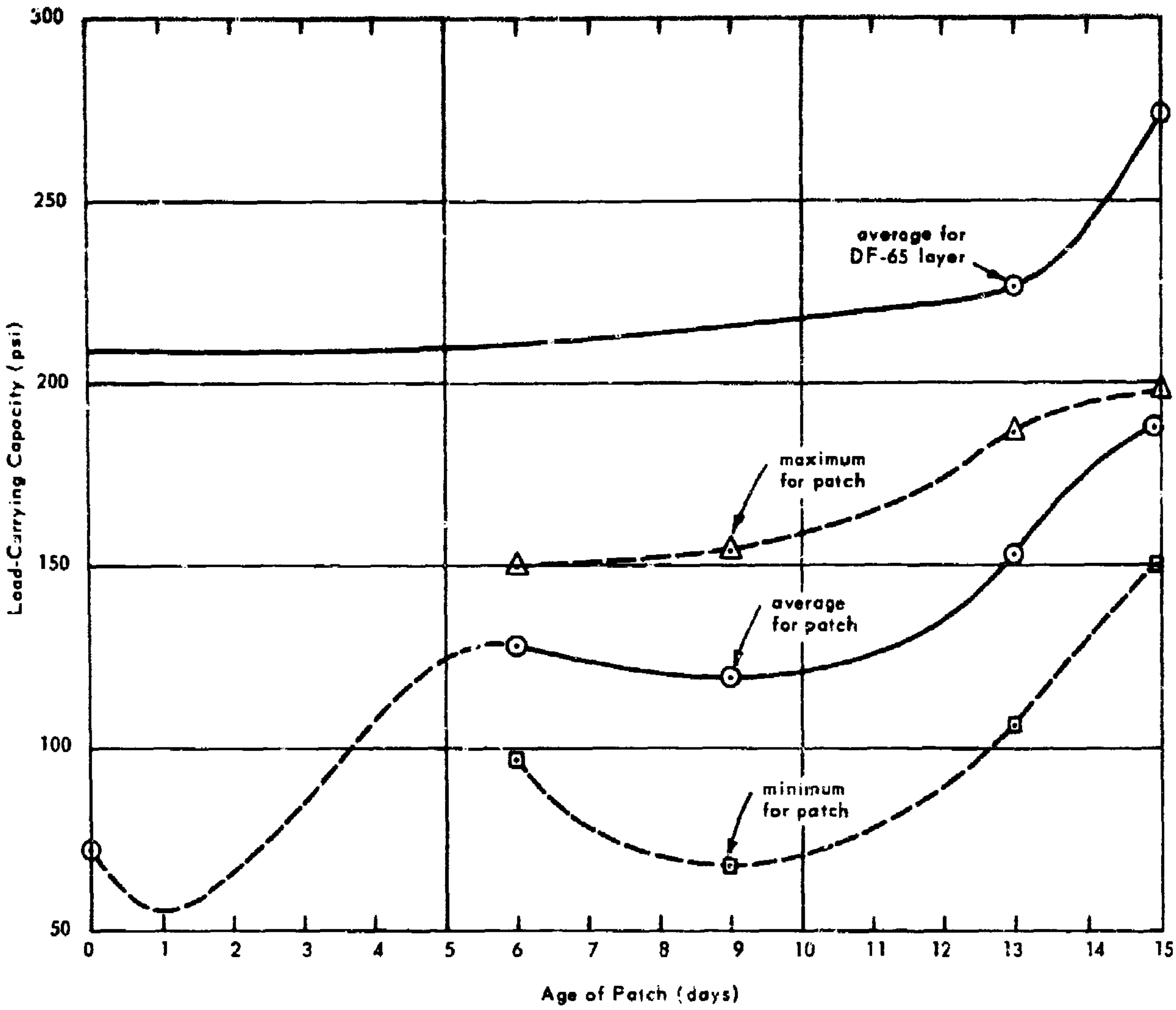


Figure 14. Growth of strength in the 29 December 1964 snow mixer patch at Station 30+00.



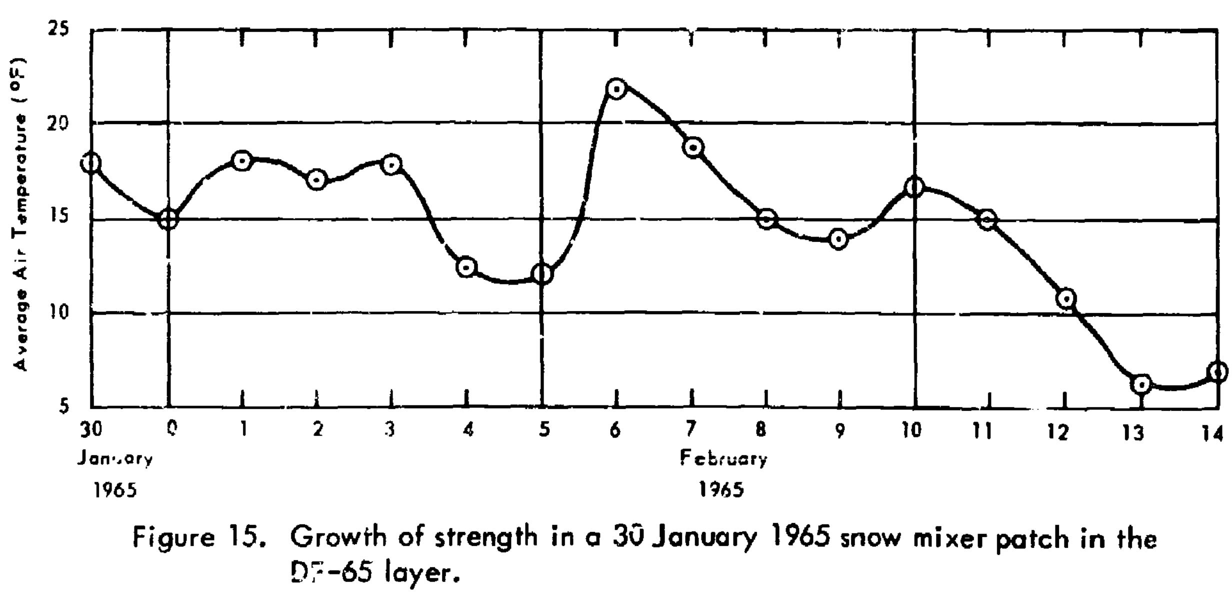


Figure 15. Growth of strength in a 30 January 1965 snow mixer patch in the DF-65 layer.

The prevailing air temperature appeared to influence the temperature of both the natural and compacted snow to a depth of 5 feet. The temperature lag time in the natural snow was about 6 hours; in the compacted snow it was considerably less. Under warm north winds and a complete cloud cover, the temperature in the top 2 feet of the compacted snow gradually increased to 25°F during one 3-day period in January 1965. Several days of clear skies and diurnal temperatures between 25°F and 10°F were required to reduce this temperature to 20°F. Such reduction was necessary as snow temperatures above 20°F have an adverse influence on strength, bearing capacity, and surface hardness of compacted snow.[14]

STRATIGRAPHY OF THE NATURAL SNOW

The stratigraphy of the natural snow cover on the 70-140 area (Figure 1) at Station 100+00 was observed at the beginning and end of the summer season. These observations, made on 27 October 1964 and on 13 February 1965, are presented in Tables 2 and 3.

Table 2. Stratigraphy of the Natural Snow at the NCEL Test Site on 27 October 1964

Depth Below Surface (in.)	Description
0-9	Moderately hard, very fine grained drift snow banded at intervals about 1 cm apart
9-13	Very hard, fine-grained drift snow 0.4 mm in size
13-16	Moderately hard, fine-grained drift snow 0.5 mm in size
16-18	Very hard, fine-grained drift snow
18-20	Moderately hard drift snow 0.5 to 1.0 mm in size
20-26	Fairly soft, loosely consolidated granular snow about 0.1 mm in size
26-29	Coarse-grained snow with depth hoar crystals near surface of DF-64 compacted-snow layer
29	Surface of DF-64 compacted-snow layer

Table 3. Stratigraphy of the Natural Snow at the NCEL Test Site on 13 February 1965

Depth Below Surface (in.)	Description
0-2	Fresh, very fine, fluffy new-fallen snow and drift
2-6	Hard, medium-grained, well-packed drift snow 0.5 to 1.0 mm in size
6-11	Loose, poorly consolidated, medium-grained corn snow 1.0 to 2.0 mm in size
11	Thin layer of very hard, very fine grained drift snow
11-11½	Loose, poorly consolidated, medium-grained corn snow 1.0 to 2.0 mm in size
11½-14½	Thin layer of very hard, very fine grained drift snow
11½-14½	Loose, poorly consolidated, medium-grained corn snow 1.0 to 2.0 mm in size
14½	Thin layer of very hard, very fine grained drift snow
14½-19	Loose, coarse-grained corn snow 2.0 to 3.0 mm in size
19-22	Large depth hoar crystals with sporadic voids up to ¼-inch high above DF-64 compacted-snow layer
22	Surface of DF-64 compacted-snow layer

At the beginning of the summer season, the winter-old natural snow cover on the 70-140 area was 29 inches deep (Table 2). Its grain size varied from 0.4 mm near the surface to 1.0 mm 24 inches below the surface, and a 3-inch band of coarse-granular snow and depth hoar crystals existed just above the DF-64 layer of compacted snow in this area. The density of this snow was 0.34 gm/cm^3 6 inches below the surface and 0.40 gm/cm^3 18 inches below the surface.

At the end of the summer season, the natural snow cover on the 70-140 area snow was only 22 inches thick, or 7 inches less than at the start of the season. Its grain size varied from 0.5 mm near the surface to 3.0 mm 18 inches below the surface, and the 3-inch band of depth hoar crystals just above the DF-64 layer of compacted snow in this area were larger and more pronounced. The density of this snow was 0.48 gm/cm^3 4 inches below the surface and 0.42 gm/cm^3 18 inches below the surface, representing an increase of about 16% during the summer season.

PART IV. AIRCRAFT TESTS

On 2 December the 10-70 area (Figure 1) was marked for aircraft testing. It was first tested with a C-47 aircraft on wheels on 3 December. Starting on 6 December, it was tested with LC-130F aircraft on wheels at approximately 2-week intervals until 14 February.

RUNWAY MARKERS

Fuel drums were used to mark the 10-70 area for aircraft testing. Two upright drums side by side were placed on both sides of the runway at 1,000-foot intervals, with single upright drums in between to mark the 500-foot intervals. In each case the inside drums were set flush with the area sides. Those at every 1,000 feet were stenciled 0 to 6 in large numbers, from both east to west and west to east. At the barrier or west end of the area, the longitudinal centerline was marked with five end-to-end drums on their sides. The shelf or east end was marked with a row of 6-inch-high red flags 25 feet apart across the area.

25,000-POUND C-47 TEST

Arrangements were made on 2 December to test the 10-70 area with a C-47 aircraft weighing 25,000 pounds on 3 December. The landing gear on this aircraft consists of two main wheels and a tail wheel. All three wheels were fitted with skis.

Test Conditions

Snow Strength. In preparation for the C-47 test, the confined-shear strength in the 16-inch DF-65 layer of compacted snow was tested in a random pattern at eight locations on 2 December. Three cores were tested at each location. Based on these tests, the average load-carrying capacity in the 8-day-old layer of compacted snow was 162 psi; the maximum 235 psi, and the minimum 113 psi (Figure 13). In the top 4 inches the confined-shear strength ranged from 16.4 to 56.6 psi, for an average of 39.9 psi; in the middle 8 inches, from 23.9 to 60.2 psi for an average of 43.4 psi; and in the bottom 4 inches, from 20.0 to 53.8 psi for an average of 35.4 psi.

Weather. Visibility was excellent for the 3 December aircraft test. There were no clouds and the wind from the north was less than 5 mph. The average air temperature during the 24 hours preceding the test was 21°F, with a maximum temperature of 34°F at the time of the test, and a minimum of 13°F 24 hours before it.

Test

The C-47 aircraft landed on skis on the 10-70 area at 0900 hours. The tires on its two main wheels were inflated to 60 psi and its tail-wheel tire to 30 psi. Because of the prevailing wind, the aircraft landed on the shelf or east end of the area (Figure 2). It touched down near Station 60+00 and came to a stop near Station 20+00, where the pilot turned it around on skis and taxied back to Station 30+00. After a slight pause, he lifted the skis and slowly taxied on wheels to Station 65+00 and back to Station 15+00. He then made a high-speed serpentine taxi test run back to Station 60+00. Starting at Station 60+00, he took off on wheels in 1,500 feet, circled the area, and made a wheel landing (Figure 16), a second takeoff and a second landing. The copilot then made a wheel takeoff and two touch-and-go wheel landings and takeoffs to complete the test.

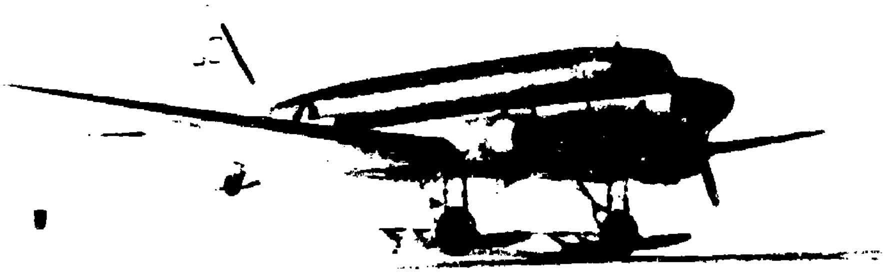


Figure 16. C-47 aircraft making a wheel landing on the 10-70 test area on 3 December 1964.

Observations

The aircraft was on skis for 5,000 feet and on wheels for 24,000. It was difficult to find the ski tracks, but the surface of the area was soft enough in most places for the main wheels to mark it with 1/4- to 1/2-inch-deep indentations. In a few places, the tracks were up to 1-1/2 inches deep. The soft surface at no point impeded the mobility of the aircraft, and permitted good braking action on turns and landings. At one point during the test, the aircraft was parked on its wheels for 15 minutes; on resumption of the test, it rolled off with ease.

The pilot commented favorably on the smoothness of the surface and the braking performance of the aircraft in turns and stops. He stated that the area was easy to define from the air and that the barrel markers and the smooth surface were suitable for good, easy landings and takeoffs. He said there was no noticeable bounce or rocking of the aircraft at any time, either on skis or on wheels.

90,000-POUND LC-130F TEST

On 5 December, arrangements were made to test the 10-70 area with an LC-130F aircraft weighing 90,000 pounds on a return flight from Byrd Station. The landing gear on this aircraft consists of tandem main wheels 14 feet 3 inches apart fitted with skis and a dual nose wheel fitted with a ski. The main wheel tires are 20.00 x 20 and the nose wheel tires are 12.50 x 16.

Test Conditions

Snow Strength. No snow strength tests were made for the 6 December test; instead, the 2 December strength tests were used as an index of strength.

Weather. Visibility was excellent for the 6 December aircraft test. There were no clouds and the wind, a warm breeze from the north, was less than 10 mph. The average air temperature during the 48 hours preceding the test was 23°F, with highs of 30°F each day and lows of 12°F each night. This, coupled with the solar radiation, which reached 1 Langley per minute between 1500 and 1600 hours each day, resulted in a near-thaw snow surface at the time of the test.

Test

The LC-130F aircraft landed on skis on the 10-70 area at 1500 hours. The tires on its four main wheels were inflated to 95 psi, and its two nose-wheel tires to 45 psi. Because of the prevailing wind, the aircraft landed on the barrier, or west end of the area. It touched down near Station 15+00 and came to a stop near Station 30+00, where the pilot lifted the skis and slowly taxied on wheels to Station 58+00 (Figure 17). He then executed a backup turnaround (a series of maneuvers

including use of reverse propeller pitch), and taxied back down the area to Station 13+00. Here, he turned around again and came to a stop at Station 15+00. After a short pause, he made a 1,500-foot takeoff on wheels (Figure 18). After circling the area, he landed on wheels at Station 24+00 and, using brakes, stopped at Station 45+00. The pilot then turned around at Station 47+00 and taxied back to Station 13+00, where he turned around in the wheel tracks made in the first turn at this location (Figure 17). He made a second wheel takeoff between Stations 15+00 and 30+00, and a touch-and-go landing on wheels between Stations 25+00 and 38+00. The test was completed at 1532 hours.

Observations

The aircraft was on skis for 1,500 feet and on wheels for 18,700 feet (11,900 feet while taxiing and turning and 6,800 feet while taking off and landing). The takeoffs required 1,700 feet; the landing with brakes, 2,100 feet. The aircraft rolled freely at all times while taxiing, taking off, and landing. The full-stop landing on wheels was soft and gentle; the touch-and-go landing was hard — the aircraft hit, bounced off and hit again before it rolled on the surface.

The surface of the area was soft enough in most places for the main wheels of the LC-130F to mark it with 1-inch-deep tracks. In returning to Station 13+00 after the first landing, the aircraft doubled back in its own tracks. The double set of tracks in this 3,400-foot taxi run was no deeper than the original single set except for one 4-inch-deep, 50-foot track near Station 22+00. Examination showed that the surface snow at this location was very soft but the underlying snow in the wheel track hard and undisturbed.

In the double turnaround near Station 13+00 (Figure 17), the tandem main wheels crossed one spot six times. The tracks in the six-track crossing were 2 inches deep compared with the 1-inch-deep single and double tracks in the turn. The underlying snow in all of the wheel tracks in the turn area was hard and undisturbed. Small berms of snow about 1/2 inch high were formed on each side of the 1-inch-deep wheel tracks; these berms were 1 to 2 inches high along the 2- to 4-inch-deep wheel tracks.

Failures in the DF-65 Layer

Two failures occurred in the DF-65 layer during the 6 December aircraft test. One was near Station 45+00 where the aircraft was moving across the test area in a sharp turn, and another near Station 46+50 where one set of the tandem main wheels backed across its own tracks in a turn. Both failures were confined; that is, the aircraft crossed the areas where the failures occurred without a loss of speed or mobility.

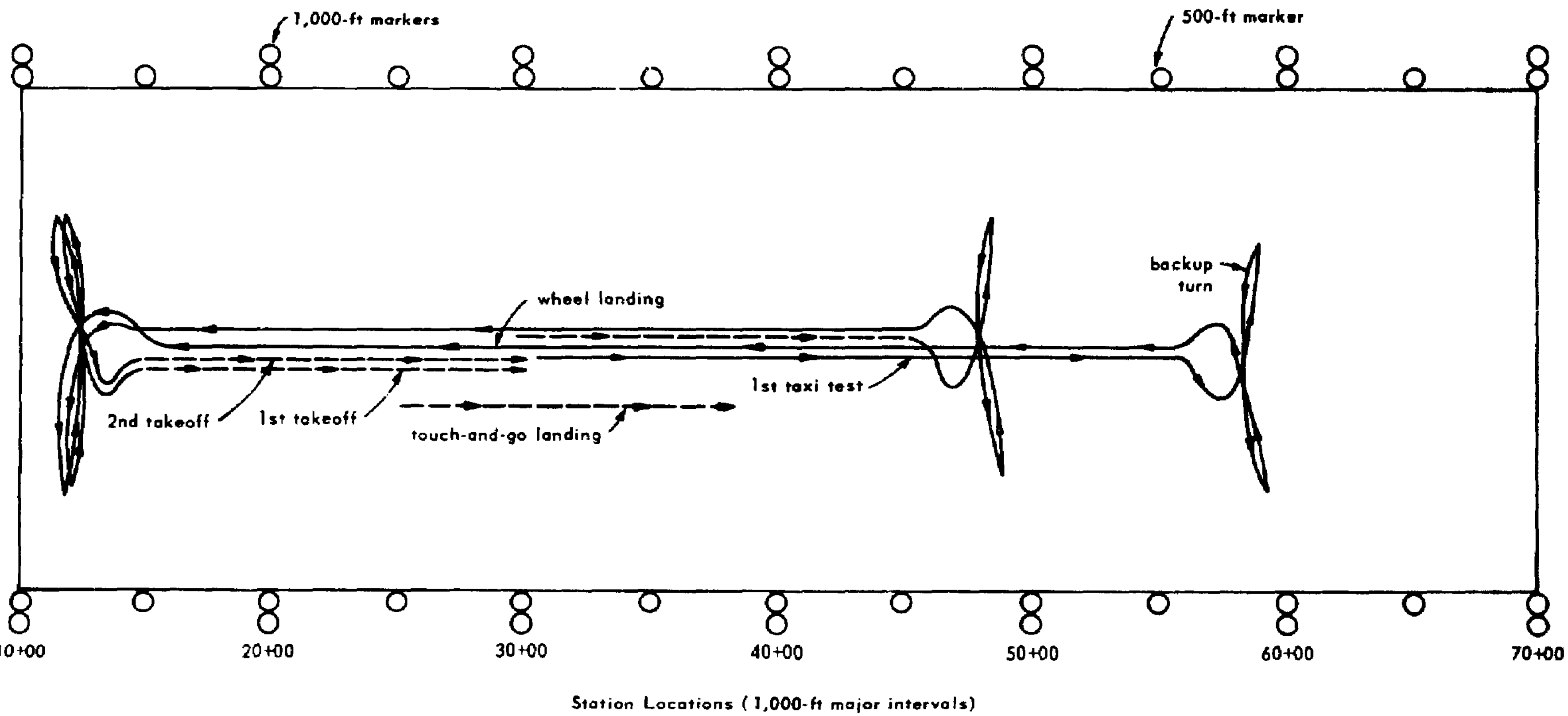


Figure 17. LC-130F aircraft traffic pattern on 10-70 test area in 6 December 1964 test.

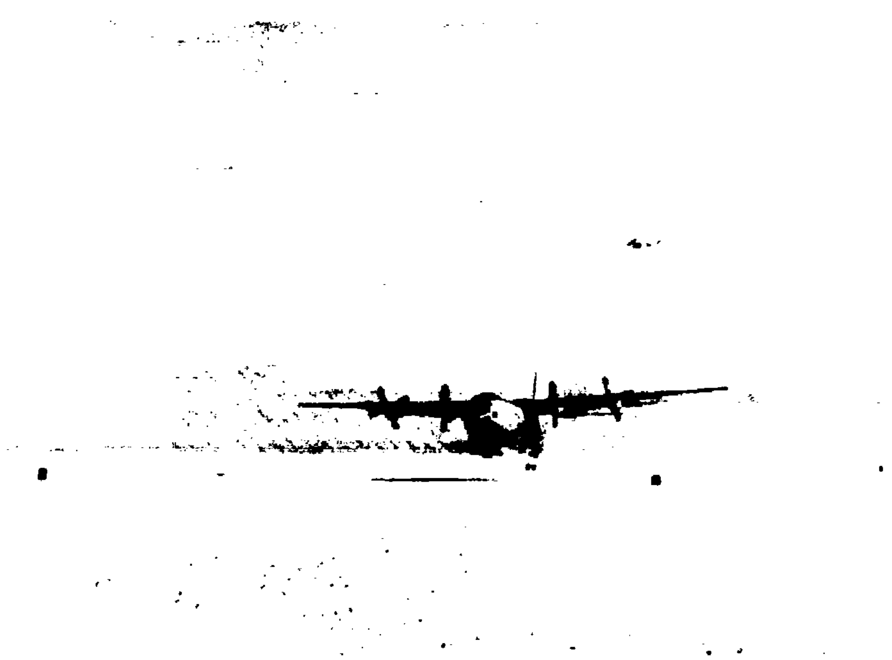


Figure 18. LC-130F aircraft making a wheel takeoff in the 10-70 test area on 6 December 1964.

In the turn at Station 45+00, the aircraft was moving at a 30-degree angle to the centerline of the area when it crossed a 2-foot strip of snow where the 95-psi main wheels indented the surface to a depth of 3 inches (Figure 19). Examination showed that the aircraft crossed a between-mixer-lane partial-processing miss (see Repairs, Part II) in the DF-65 layer which tapered out and disappeared about 25 feet beyond either side of the crossing.

The snow in the miss was completely disaggregated and compacted at the wheel crossing, but the adjacent snow in the DF-65 layer and the underlying DF-64 layer of compacted snow was undisturbed. The size, orientation, and containment of the miss coupled with its relatively high-density snow permitted the aircraft to roll across the failure without difficulty. The nose wheels also crossed the miss but they only marked the surface with their tire prints.

As measured by confined shear, the load-carrying capacity of the partially processed snow in the miss at Station 45+00 was 79 psi, or only 62% of the 127-psi load-carrying capacity in the fully processed layer of snow adjacent to the miss. It was less than one-half of the 162-psi average load-carrying capacity established for the DF-65 layer on 2 December. The average density of the snow in the miss was 0.56 gm/cm^3, or the same as the average for the once-processed snow in the DF-65 layer.

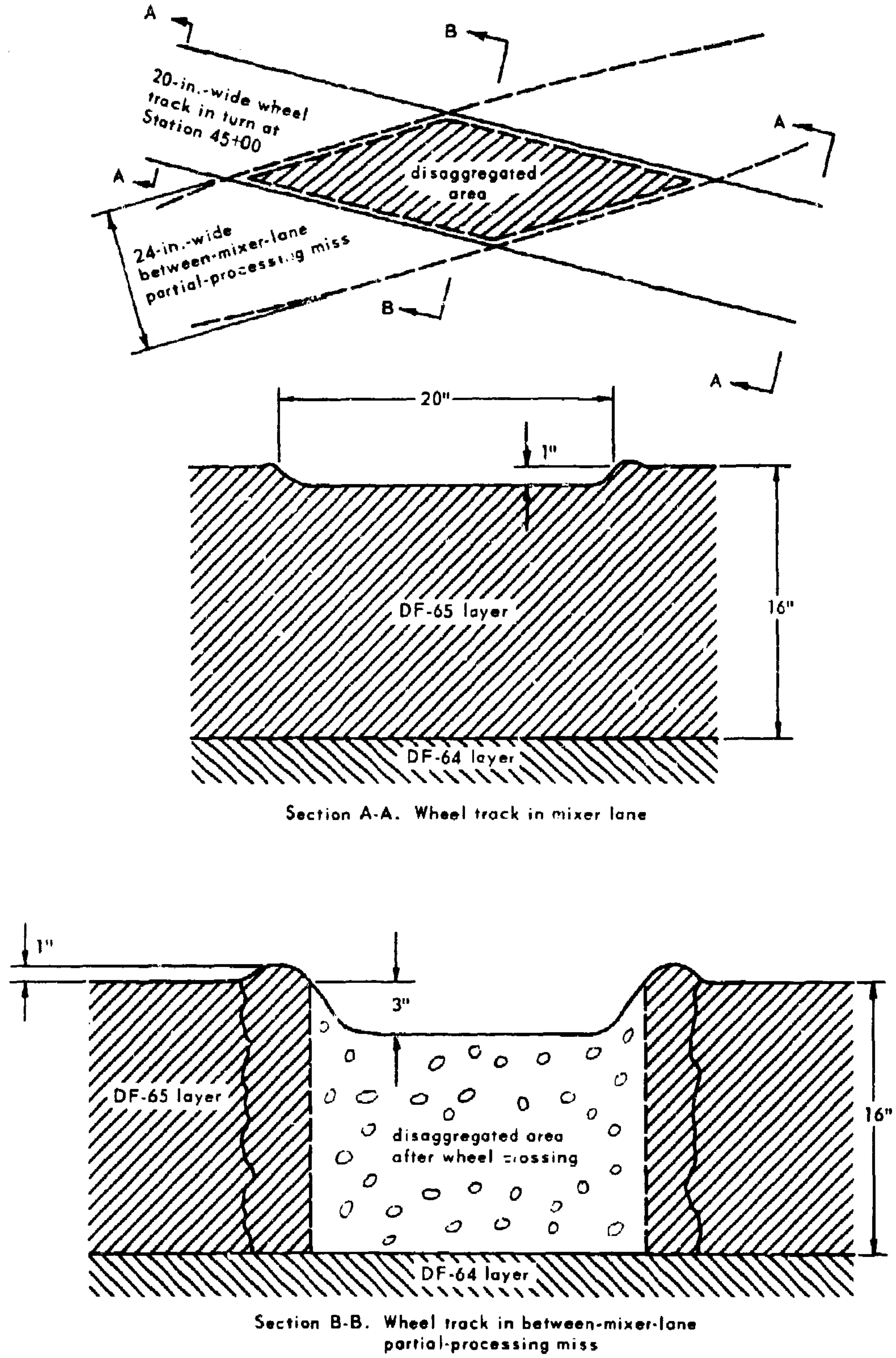


Figure 19. Failure under main wheels of LC-130F aircraft at Station 45+00 on 6 December 1964.

In the turnaround at Station 46+50 (Figure 17) the average load-carrying capacity in the DF-65 layer was only 106 psi, or about 35% less than the 162-psi average established for the whole layer on 2 December. This snow supported the aircraft with ease in both forward and reverse motion and, except for the small between-mixer-lane partial-processing miss described below, the wheel tracks in the turn were 1 inch or less in depth. The miss, which was 1 foot wide at the crossing and 10 feet long, was crossed twice in the same spot by one set of main wheels. The wheel track was 3 inches deep at the crossing and the snow directly under the wheels was disaggregated to a depth of 8 inches. Examination showed that the load-carrying capacity of the snow in the miss was 73 psi, or slightly less than the load-carrying capacity of the snow in the miss at Station 45+00. The between-mixer-lane partial-processing miss near Station 45+00 was repaired with a water patch on 20 December (see Repairs in Part II). This repair was delayed by the 7-11 December storm.

102,000-POUND LC-130F TEST

On the morning of 24 December, arrangements were made to test the 10-70 area with an LC-130F aircraft tanker on a return flight from Byrd Station. Before the test, the aircraft was flown back to Williams Field to be loaded to a gross test weight of 102,000 pounds.

Test Conditions

Snow Strength. Just prior to the aircraft test, the confined-shear strength in the DF-65 layer was tested in a random pattern at nine locations on 24 December. Three cores were tested at each location. Three of the test locations were along the centerline of the area and three along each side 25 feet in.

Based on these tests, the average load-carrying capacity in the 30-day-old layer of compacted snow was 143 psi, or about 11% less than on 2 December (Figure 13); the maximum load-carrying capacity was 208, and the minimum 90 psi. In the top 4 inches, the confined-shear strength ranged from 13.4 to 45.6 psi for an average of 33.7 psi; in the middle 8 inches, from 16.7 to 51.4 psi for an average of 34.1 psi; and in the bottom 4 inches, from 7.9 to 67.8 psi for an average of 41.4 psi.

The minimum load-carrying capacity of 90 psi was found in the middle of the area at Station 45+00. Based on the 6 December test, the strength of the snow at this location appeared marginal for support of the LC-130F aircraft on wheels. The confined-shear strength in the top 8 inches of this snow averaged 24.8 psi, indicating good processing, but from 8 to 12 inches it averaged only 14.0 psi, indicating the absence of processing.

Weather. Visibility was very poor for the 24 December aircraft test. The sky was overcast, surface definition marginal because of low, light surface drifting, and the wind was blowing from the southeast at speeds of 10 to 18 mph. The average air temperature during the 48 hours preceding the test was 20°F, the maximum 26°F, and the minimum 17°F. These temperatures were well below freezing, but the daily input of solar radiation resulted in a near-thaw temperature in the snow surface and higher snow temperatures with depth than those that existed in early December.

Test

The LC-130F aircraft landed on skis on the 10-70 area at 1326 hours. The tires on its main wheel were inflated to 85 psi, and its nose-wheel tires to 45 psi. Because of the prevailing wind, the aircraft landed on the barrier , or west end of the area. It touched down near Station 15+00 and taxied to Station 68+00 where it turned around on skis and came to a stop. After a short delay the pilot raised the skis and taxied on wheels at an average speed of 25 mph to Station 12+00, where he made a backing turn and a wheel takeoff between Stations 15+00 and 30+00. After circling the area he landed on wheels at Station 29+00, braked to a stop at Station 50+00, and turned around at Station 52+00. The pilot then made a second 25-mph taxi run down the middle of the area following his original wheel tracks. During this run the right wing of the aircraft dipped noticeably at Station 50+00 and the main wheels appeared to plow the surface at Station 45+00; otherwise, the aircraft traveled smoothly and easily. At Station 27+00, the pilot made a backing turn a third time in his wheel tracks, to Station 35+00. At this point, he got out of the aircraft and examined the test area. He then made a wheel takeoff between Stations 35+00 and 51+00 to complete the test at 1436 hours.

Observations

The aircraft was on skis for 5,300 feet and on wheels for 16,200 feet (11,000 feet while taxiing and turning and 5,200 feet while taking off and landing). The two takeoffs required 1,500 and 1,600 feet; the landing with brakes, 2,100 feet. The aircraft rolled freely and easily at all times while taking off and landing.

The surface of the area was covered with 2 to 6 inches of drift snow during this test. As a result, the wheel tracks were 2 to 4 inches deep over most of the area. Double and triple passes of the aircraft in the same tracks did not increase the depth of these tracks except where the DF-65 layer failed during the aircraft test.

Failures in the DF-65 Layer

During the first taxi run down the middle of the area, the DF-65 layer failed at Station 45+00 and at Station 50+00. Both of the failures were confined; that is, the aircraft crossed the areas of failure without a loss of speed or mobility on its

wheels. During this taxi run, the snow in the failures was disaggregated and compacted about 3 inches under the wheels; in the second taxi run most of this disaggregated snow was displaced and deposited alongside the wheel track. It quickly built up to a height sufficient for the aircraft skis, which are about 8 inches above the bottom of the tires when in a raised position, to support most of the load. Once the aircraft passed through the failures, the wheels climbed back onto the compacted surface and the aircraft was again supported on them.

Examination of the 10-70 area after the test showed that the DF-65 layer of compacted snow in the failure areas at Stations 45+00 and 50+00 was only 8 inches thick and seams of unprocessed snow up to 4 inches thick separated this layer from the DF-64 layer (see Repairs in Part II). By confined-shear measurement, the load-carrying capacity of the 8-inch-thick layer of compacted snow was 50 psi at Station 45+00 and 59 psi at Station 50+00; the confined-shear strength in the 4-inch-thick seams of unprocessed snow between this layer and the DF-64 layer was less than 10 psi. These two conditions resulted in wheel breakthroughs at these locations in the second taxi run. Strength measurements on the 10-70 area before the aircraft test indicated an area of potential failure at Station 45+00; no measurements were made at Station 50+00.

The size and shape of the between-layer seams of unprocessed snow at Stations 45+00 and 50+00 were determined by Rammsonde probing on 25 December. During this examination, another between-layer seam of unprocessed snow was found at Station 30+00 and a between-mixer-lane partial-processing miss near Station 35+00. These zones of low-strength snow were repaired with snow mixer patches between 26 and 29 December.

Wheel Track Strength Tests

Following the 24 December aircraft test, 22 confined-shear tests were made at random locations alongside the 15,000 feet of aircraft tracks where no failures occurred. Based on these tests, the average load-carrying capacity in the DF-65 layer was 140 psi, or within 2% of the load-carrying capacity determined by the 27 confined-shear tests made just prior to the aircraft test.

The maximum load-carrying capacity determined by the wheel track strength tests was 175 psi and the minimum 103 psi. This maximum was 16% less than that found in the strength tests before the aircraft test, and the minimum 14% more. In the wheel track test, the confined-shear strength in the top 4 inches of the compacted snow averaged 34.4 psi, the middle 8 inches 33.5 psi, and the bottom 4 inches 38.8 psi. These averages varied 2 to 8% from those found in the strength tests before the aircraft test.

115,000-POUND LC-130F TEST

On 10 January arrangements were made to test the 10-70 area on 11 January with an LC-130F aircraft tanker on a return flight from Pole Station. Before the test, the aircraft was returned to Williams Field where it was loaded to a gross test weight of 115,000 pounds.

Test Conditions

Snow Strength. In preparation for the 11 January aircraft test, the confined-shear strength in the DF-65 layer was tested at 10 locations along its centerline on 10 January. Three cores were tested at each location. At the time of the strength tests the air temperature was 24°F, the average temperature in the top foot of the compacted snow 25°F, with that in the second foot 24°F.

Based on these tests, the average load-carrying capacity in the 47-day-old layer of compacted snow was 146 psi, or 2% more than on 24 December and 10% less than on 2 December (Figure 13). The maximum load-carrying capacity was 159 psi and the minimum 101 psi. In the top 4 inches, the confined-shear strength ranged from 27.2 to 47.8 psi for an average of 37.1 psi; in the middle 8 inches, from 31.6 to 45.3 psi for an average of 36.0 psi; and in the bottom 4 inches, from 28.3 to 51.0 psi for an average of 37.1 psi.

The minimum load-carrying capacity of 101 psi was found in the middle of the area at Station 60+00. Based on the 24 December test, the strength of the snow at this location appeared marginal for support of the LC-130F aircraft on wheels. The confined-shear strength in the top 12 inches of this snow averaged 30.3 psi, indicating good processing, but from 12 to 16 inches it averaged less than 10 psi, indicating the absence of processing. This finding was supported by the fact that the snow was soft and granular in texture. These tests also indicated that the surface of the DF-65 layer was uniformly hard and strong.

Weather. Visibility was excellent for the 11 January aircraft test. There were no clouds and the wind from the east was only 3 to 4 mph. The average air temperature during the 48 hours preceding the test was 18°F, the maximum 26°F, and the minimum 6°F. During the aircraft test the air temperature rose from 24° to 32°F. The average temperature in the top foot of the compacted snow was 24°F, and that in the second foot 23°F.

Test

The LC-130F aircraft landed on skis on the 10-70 area at 0905 hours. The tires on its main wheels were inflated to 85 psi and its nose-wheel tires to 45 psi. Because of the prevailing wind, the aircraft landed on the barrier, or west end of the area. It touched down at Station 15+00 and came to a stop at Station 40+00.

The pilot immediately raised the skis and taxied on wheels to Station 68+00, where he made a U turn and taxied back to Station 13+00 at an average speed of 25 mph. He made a backup turn at Station 13+00 and came to a full stop at Station 15+00. After a short pause he took off on wheels between Stations 15+00 and 35+00, circled the area and landed on wheels at Station 25+00. Using brakes, he came to a stop at Station 46+00. He then made a high-speed taxi run to Station 68+00, wheeled about, and took off on wheels between Stations 66+00 and 45+00 to complete the test at 0925 hours.

Observations

The aircraft was on skis for 2,500 feet and on wheels for 17,600 feet (11,400 feet while taxiing and turning and 6,200 feet while taking off and landing). The two takeoffs required 2,000 and 2,100 feet; the landing with brakes, 2,100 feet. The aircraft rolled freely and easily at all times while taxiing, taking off, and landing. The two turns at each end of the area were made in the same wheel tracks without indenting the surface.

The aircraft only marked the surface with its tire prints in 34,500 lineal feet of track. Indentations from 1 to 6 inches deep occurred under one or the other set of main wheels in 1,700 feet of track. Examination showed that all but one of these wheel tracks were made in areas of low-strength snow. That is, the wheel caused a confined failure but there was sufficient compressive strength in the disaggregated snow under the wheel to support the moving aircraft without a loss of speed or mobility.

Failures in the DF-65 Layer

Examination of the 10-70 area after the aircraft test showed that a progressive failure occurred at Station 60+00 because of a 4-inch-thick seam of unprocessed snow between the DF-65 and DF-64 layers. The aircraft trafficked this area four times during the test. In the first trip one set of main wheels made a 1-inch-deep, 168-foot-long track. In the second trip, with the path offset about 6 feet, the track was 3 inches deep. In the third trip, the path offset about 3 feet from the second trip, the track was 6 inches deep. In this trip a 50-foot section of compacted snow between the second and third tracks was dislodged and thrust up on its side. In the fourth trip, with the path offset about 6 feet from the third trip, the aircraft wheels only marked the surface with their tire prints.

In the area of failure the DF-65 layer of snow was only 12 inches thick; its load-carrying capacity averaged 85 psi, with a maximum of 93 psi, and a minimum of 76 psi. On the third trip this zone of low-strength snow began to fail and break up. To either side of the failure, the DF-65 layer was 16 inches thick and rested directly in the DF-64 layer. The average load-carrying capacity outside the failure area was 140 psi, or within 5% of the average established for the DF-65 layer in the 10 January strength tests.

In addition to this failure area a 3-inch-deep, 220-foot-long track occurred near Station 58+00, a 2-inch-deep, 80-foot-long track near Station 45+00, and a 3-inch-deep, 70-foot-long track near Station 65+00. Also, tracks from 1 to 4 inches deep and 45 to 241 feet long occurred near Stations 19+00, 20+00, 29+00, and 30+00.

Examination of these tracks showed that all but one occurred in between-mixer-lane misses where the load-carrying capacity in the top 8 to 10 inches of work-hardened snow ranged from 60 to 87 psi and the confined shear strength in the next 4 to 8 inches was only 10 to 15 psi (Figure 20). When the aircraft wheel passed over these misses the layer of low-strength snow compressed under the wheel and the layer of strong work-hardened snow sheared and disaggregated. The average load-carrying capacity of the snow in the DF-65 layer adjacent to these between-mixer-lane misses was 164 psi or 12% more than the average for this layer in the 10 January strength tests.

The 1-inch-deep, 100-foot-long track at Station 30+00 resulted from a zone of soft snow on the surface of the DF-65 layer which had a load-carrying capacity of 155 psi in this area. The load-carrying capacity of the surface snow was only 15 psi compared to 35 psi over most of the 10-70 area during the aircraft test. Previous aircraft tests[3] show that a load-carrying capacity of 25 psi is needed in the top 4 inches of compacted snow to support a 90-psi wheel load without disaggregation under the load.

Probing the 10-70 area with a Rammsonde showed that an intermittent between-mixer-lane miss existed along the middle of the area between Stations 10+00 and 35+00, and short between-mixer-lane misses near Stations 45+00 and 65+00. Probing also showed that a small between-layer seam of unprocessed snow existed at Station 20+00, and the between-layer seam of unprocessed snow at Station 60+00 covered a fairly large area (Figure 6). These zones of low-strength snow were repaired with snow-mixer patches between 13 and 16 January.

125,000-POUND LC-130F TEST

On 21 January arrangements were made to test the 10-70 area on 23 January with an LC-130F aircraft tanker loaded to a gross weight of 125,000 pounds. Because of flight schedules, this test was delayed until 24 January.

Test Conditions

Snow Strength. In preparation for the aircraft test, the confined-shear strength in the DF-65 layer was tested on 21 January. At the time of these tests, the average temperature in the top foot of the compacted snow was 23°F, and that in the second foot was 24°F. A spot check of the strength across the middle of the area was made at Station 40+00 on 23 January and another check at Station 30+00 on 24 January.

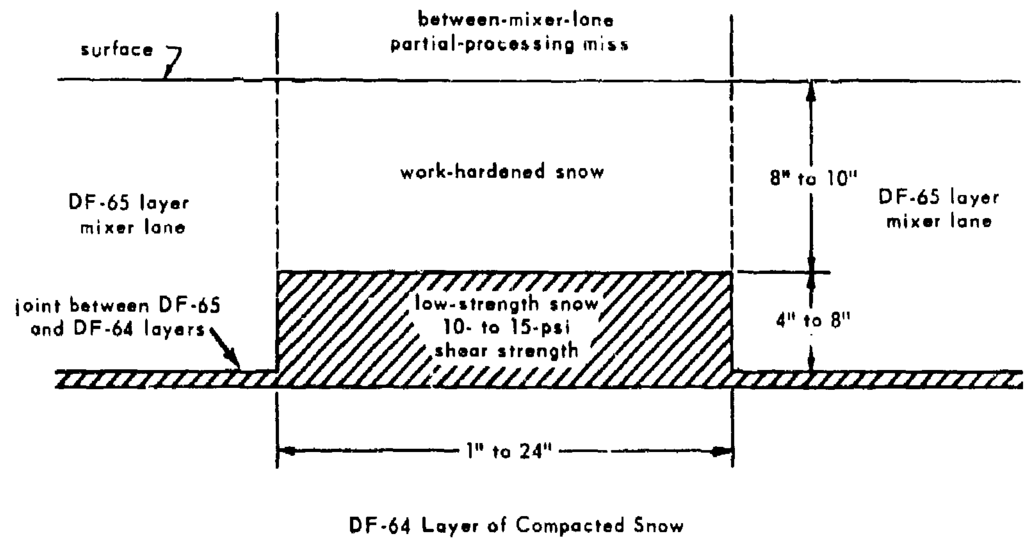


Figure 20. Cross section of a between-mixer-lane partial-processing miss in the DF-65 layer of compacted snow in 11 January 1965 test.

Based on the 21 January strength tests, the average load-carrying capacity of the 58-day-old layer of compacted snow was 172 psi or 15% more than on 11 January and 6% more than on 2 December (Figure 13). The maximum load-carrying capacity was 200 psi and the minimum 128 psi. In the top 4 inches the confined-shear strength ranged from 34.3 to 64.2 psi for an average of 46.3 psi; in the middle 8 inches, from 30.9 to 60.8 psi for an average of 40.8 psi; and in the bottom 4 inches, from 39.3 to 51.9 psi for an average of 44.2 psi.

The snow mixer patches following the 11 January aircraft tests were also tested for confined-shear strength on 21 January. Based on these tests, the average load-carrying capacity in these patches, which were made on 15 and 16 January, was 137 psi or only 20% less than the average in the DF-65 layer. The maximum load-carrying capacity in the patches was 169 psi and the minimum 109 psi. In the top 4 inches of the patches the confined-shear strength ranged from 16.2 to 49.9 psi for an average of 37.8 psi; in the middle 8 inches, from 20.0 to 54.2 psi for an average of 32.7 psi; and in the bottom 4 inches, from 16.7 to 53.3 psi for an average of 33.4 psi.

On 23 January, cores from four locations across the middle third of the area at Station 40+00 were tested for confined-shear strength. Based on these tests, the average load-carrying capacity at this location was 147 psi, the maximum 159 psi, and the minimum 138 psi. The average load-carrying capacity for this location was about 15% less than the average for the DF-65 layer on 21 January.

On 24 January cores from four locations across the middle third of the area at Station 30+00 were tested for confined-shear strength. Based on these tests, the average load-carrying capacity at this location was 164 psi, the maximum 205 psi, and the minimum 131 psi. The average load-carrying capacity for this location was 12% higher than the average at Station 40+00 and 5% less than the average for the DF-65 layer on 21 January. The confined-shear-strength measurements at one location in this test indicated the possibility of a between-mixer-lane miss. The average confined-shear strength in the top 8 inches of snow at this location was 31.2 psi, but the strength in the snow 8 to 12 inches below the surface was only 17.2 psi, compared with an average of 40.6 psi at this level in the other three locations.

<u>Weather.</u> A 1-inch snowfall covered the area on the morning of 23 January and again on the morning of 24 January. Both mornings the new snow was compacted with the finishing drag. At the time of the aircraft test the surface of the 10-70 area was covered with a 1/4-inch-thick layer of lightly bonded snow.

By test time on 24 January, the visibility was excellent. There were no clouds and the wind from the east was 15 mph. The average air temperature during the 48 hours preceding the test was 25°F, the maximum 32°F, and the minimum 18°F. During the test the average temperature in the top foot of the compacted snow was 23°F and that in the second foot 25°F. These snow temperatures were within 2 degrees of those in the snow during the 11 January test.

Test

The LC-130F aircraft landed on skis on the 10-70 area at 1603 hours. The tires on its main wheels were inflated to 85 psi and its nose-wheel tires to 45 psi. Because of the prevailing wind the aircraft landed on the barrier, or west end of the area. It touched down at Station 20+00 and came to a stop at Station 68+00 after turning around on skis. The pilot immediately raised the skis and made a taxi run at 25 mph down the middle of the area to Station 12+00, where he executed a backup turn and came to a stop at Station 15+00. The aircraft was on wheels at all times during this taxi run, even though the main wheels plowed into the surface on several occasions.

After a short pause, the pilot made a takeoff on wheels between Stations 15+00 and 35+00, and after circling the area landed on wheels at Station 30+00 and braked to a stop at Station 51+00. He then taxied to Station 68+00, where he made a backup turn and a taxi run back to Station 13+00, crossing, paralleling and following his original wheel tracks. Breakthroughs in the DF-65 layer (Figure 21) occurred under one or the other sets of main wheels during this taxi run and about half the weight of the aircraft was supported by one or the other main skis for distances of 10 to 247 feet. The pilot made a backup turn at Station 13+00 and a wheel takeoff between Stations 15+00 and 33+00, using an undisturbed section of the test area. The test was completed at 1635 hours.

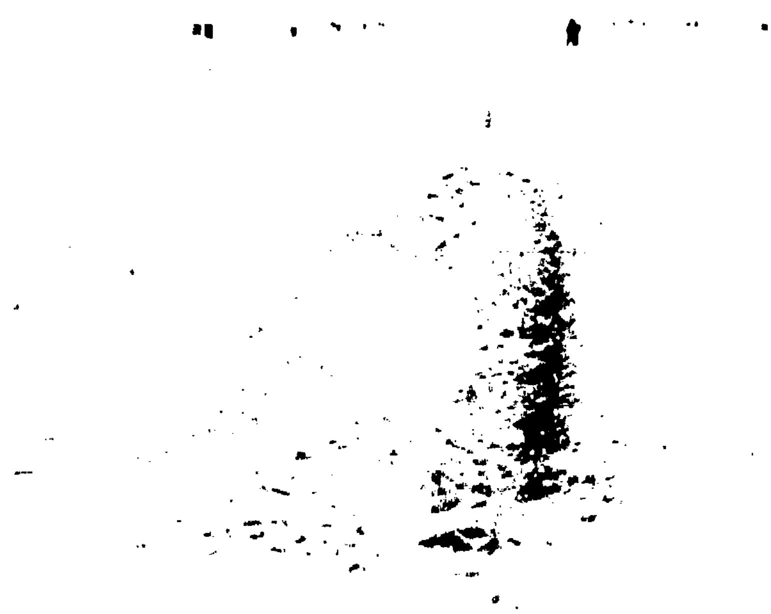


Figure 21. Wheel breakthroughs along an intermittent between-mixer-lane miss in the LC-130F aircraft test on 24 January 1965.

Observations

The aircraft was on skis for 5,200 feet and on wheels for 19,400 feet (13,300 feet while taxiing and turning and 6,100 while taking off and landing). The two takeoffs required 1,800 and 2,100 feet; the landing with brakes, 2,100 feet. In the first taxi run down the middle of the area, the aircraft rolled freely and easily even though the wheels indented the surface up to 3 inches in several places. In the second taxi run, the wheel breakthroughs caused wing pitch and some loss of speed when one or the other of the main skis was supporting the aircraft. The new-packed snow scuffed under the wheels, but except for the wheel breakthroughs, the surface was only marked with the tire prints of the aircraft wheels.

Failures in the DF-65 Layer

The wheel breakthroughs in the 24 January aircraft test occurred intermittently at 13 locations along two fairly parallel lines down the middle of the 10-70 area (Figure 22). All of the breakthroughs occurred in the 61-day-old DF-65 layer. None penetrated into the DF-64 layer and none occurred in the late-December and mid-January snow mixer patches (Figure 9). The six breakthroughs along the line closest to the south side of the area varied in length from 20 to 427 feet for an accumulated total of 1,683 feet. The wheel breakthroughs along the line closest to the north side varied in length from 10 to 328 feet for an accumulated total of 908 feet. Some of the failures occurred in the second pass over the same wheel track; others occurred in a new track. The DF-65 layer under the aircraft wheels in the breakthroughs was completely disaggregated and either thrown out of the track with resultant snow support of the ski or compacted under the wheel.

Examination of the 10-70 area after the test showed that all of the breakthroughs except one resulted from between-mixer-lane misses. The other failure, which occurred near Station 58+00, resulted from a between-layer seam of unprocessed snow.

Confined-shear measurements were made along the breakthroughs that occurred at the between-mixer-lane misses. These measurements showed that the confined-shear strength in the top 8 inches of work-hardened snow in these misses (Figure 20) ranged from 22.6 to 34.0 psi for an average of 28.3 psi; but the confined-shear strength of the snow 8 to 12 inches below the surface was 10 psi or less. The breakthroughs occurred because the strength of the work-hardened snow was not sufficient to support the load, and the shear strength of the underlying 4-inch layer of snow was not sufficient to transmit this load to the compacted snow in the DF-64 layer. When the main wheels of the aircraft passed over one of these misses, the layer of low-strength snow compacted and the work-hardened snow failed in shear and disaggregated under the wheels.

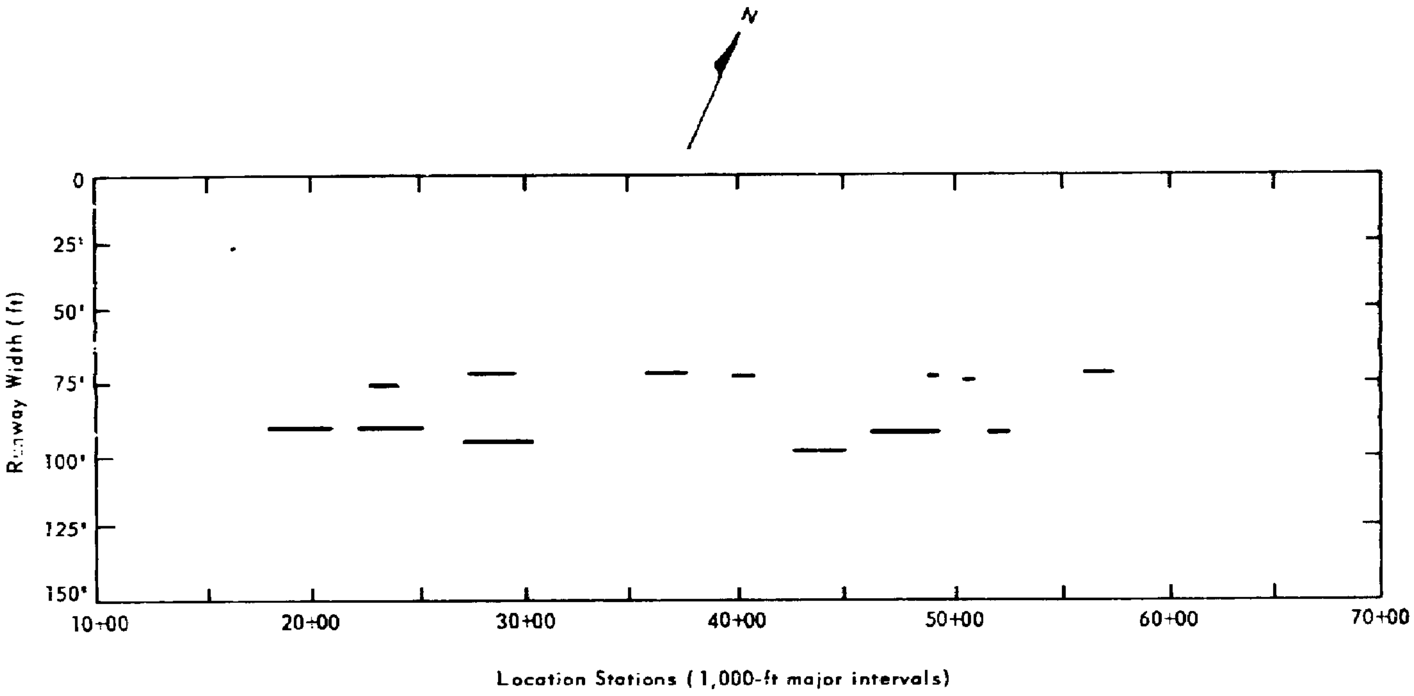


Figure 22. Location of the 13 wheel breakthroughs on the 10-70 test area in the LC-130F aircraft test on 24 January 1965.

Confined-shear measurements in the between-layer miss near Station 58+00 showed that the DF-65 layer of compacted snow was only 6 inches thick, and the seam of unprocessed snow between it and the DF-64 layer was up to 3 inches thick. The load-carrying capacity of the 6-inch layer of DF-65 compacted snow ranged from 53 to 83 psi for an average of 66 psi, and the confined-shear strength of the underlying 3-inch seam of unprocessed snow was 10 psi or less. This combination resulted in the same type of failure that occurred in the between-mixer-lane misses.

The size, shape, and length of the processing misses detected by the aircraft in the 24 January test were determined by probing the area with the Rammsonde. It was found that two parallel 4,000-foot-long, intermittent between-mixer-lane misses existed between Stations 15+00 and 55+00, and two parallel 600-foot-long between-mixer-lane misses between Stations 38+00 and 44+00. These zones of low-strength snow and the between-layer seam of unprocessed snow near Station 58+00 were repaired with snow mixer patches between 26 and 30 January.

Wheel Track Strength Tests

Following the 24 January aircraft test, 20 confined-shear tests were made at random locations alongside the aircraft tracks where no failures occurred. Based on these tests, the average load-carrying capacity in the DF-65 layer was 151 psi or 12% less than the average for this layer in the 21 January tests.

The maximum load-carrying capacity as determined in the wheel track strength tests was 198 psi and the minimum 111 psi. This maximum was 1% less than that in the 21 January test and the minimum was 13% less. In the wheel track strength test the confined-shear strength in the top 4 inches of the compacted snow averaged 40.6 psi, the middle 8 inches 35.0 psi, and the bottom 4 inches 39.9 psi. These averages varied from 10 to 14% less than those found in the 21 January tests.

135,000-POUND LC-130F TEST

The 135,000-pound LC-130F aircraft test on the 10-70 area was scheduled for 13 February, but blowing snow and calving of the barrier delayed this test until 14 February. A 400-foot section of the 10-70 area (Figure 1) broke off during the night of 13 February; however, by early morning on 14 February, the sea was calm, the barrier fairly stable, and the weather clear. As a result, two aircraft tests were made on the 10-70 area, one at midday and one in the late afternoon. Both tests were conducted with an LC-130F aircraft weighing 135,000 pounds. In the first, the tires on the main wheels were inflated to 75 psi; in the second, to 95 psi. There were no wheel indentations or breakthroughs in the compacted snow during these tests.

Test Conditions

On the morning of 14 February, the north side of the 10-70 area was clear of drift, the middle third covered with 2 to 3 inches of hard, windblown drift, and a 20-foot strip of hard drift 2 to 3 feet thick existed along the south side of the area. Strong winds and poor visibility prevented the removal of this drift for the aircraft tests. For these tests the 10-70 area was 130 feet wide and 5,500 feet long.

Snow Strength. In preparation for the 14 February test, the confined-shear strength in the DF-65 layer was tested in a random pattern on 12 February. The average temperature in the top foot of the compacted snow was 16°F and that in the second foot 15°F.

Based on these tests, the average load-carrying capacity in the 80-day-old layer of compacted snow was 220 psi, or 22% more than on 21 January and 26% more than on 2 December (Figure 13). In the top 4 inches the confined-shear strength averaged 61.2 psi; in the middle 8 inches, 56.1 psi; and in the bottom 4 inches, 46.4 psi.

The confined-shear strength in the late-January snow mixer patches was also measured on 12 February. These tests showed that the average load-carrying capacity in these patches was 154 psi (Figure 15) or 30% less than the average load-carrying capacity in the DF-65 layer. Based on the previous aircraft tests, however, the strength of the snow in these patches appeared adequate to support the aircraft.

Between the two aircraft tests on 14 February, the confined-shear strength in the DF-65 layer was again tested in a random pattern. The average temperature in the top foot of the compacted snow was 17°F and that in the second foot 19°F. Based on these tests, the average load-carrying capacity in the 82-day-old layer of compacted snow was 276 psi, or 20% more than on 12 February (Figure 13); the maximum load-carrying capacity was 332 psi and the minimum 258 psi. In the top 4 inches the confined-shear strength ranged from 56.4 to 110.8 psi for an average of 80.9 psi; in the middle 8 inches, from 58.3 to 84.9 psi for an average of 66.2 psi; and in the bottom 4 inches, from 46.4 to 85.6 psi for an average of 62.4 psi.

The confined-shear strength in the late-January snow mixer patches was also measured on 14 February. These tests showed that the average load-carrying capacity in these patches was 178 psi or 16% more than on 12 February but still over 30% less than the average for the DF-65 layer.

Between 12 and 14 February the average temperature in the top 2 feet of compacted snow increased from 16°F to 18°F. This rise would normally indicate a slight decrease in the strength of the snow; however, it appears that the snow strength was more responsive to longer range climatic changes during this period than it was to small day-to-day snow temperature changes. The solar radiation at the test site started declining in mid-January and by early February it was decreasing rapidly (Figure 13). In early February the average daily air temperature at the test site was above 20°F, but by mid-February it was below 10°F (Figure 3).

Weather. Visibility was excellent for the 14 February aircraft tests. There were no clouds and the wind from the east was only 5 to 8 mph. The average air temperature during the 60 hours preceding the tests was 7°F; the maximum 18°F, and the minimum -8°F. The air temperature was 5°F during the first test and 12°F during the second test.

First Test

The LC-130F landed on skis on the 10-70 area at 1240 hours. The tires on its main wheels were inflated to 75 psi and the nose-wheel tires to 56 psi. Because of the prevailing wind the aircraft landed on the barrier, or west end of the area. It touched down at Station 20+00 and came to a stop at Station 50+00. The pilot immediately raised the skis and taxied on wheels to Station 64+00, where he made a backup turnaround and taxied down the center of the area at a speed of 30 mph to Station 18+00. Here he made a backup turnaround and came to a stop at Station 20+00.

After a short pause, the pilot took off on wheels between Stations 20+00 and 43+00, circled the area and made a wheel landing between Stations 20+00 and 50+00. He then taxied to Station 64+00, where he executed a backup turnaround and taxied back and forth across the test area at 500-foot intervals to Station 20+00, where he made a final backup turnaround. The pilot then took off on wheels between Stations 20+00 and 40+00 to complete the test at 1304 hours.

Second Test

In the second test the LC-130F landed on wheels on the barrier, or west end of the 10-70 area, at 1700 hours. Its main wheel tires were inflated to 95 psi, the nose-wheel tires to 60 psi. The pilot touched down on wheels at Station 20+00 and came to a stop at Station 50+00. He taxied to Station 70+00, where he made a backup turnaround and taxied back down the center of the area to Station 15+00, following the tracks made in the first test. At Station 15+00 he executed a backup turnaround and after a short pause took off on wheels between Stations 15+00 and 38+00. After circling the area he made a landing on wheels between Stations 15+00 and 58+00, where he turned around and taxied for the third time in the same wheel tracks to Station 40+00. Starting at this point, he made a serpentine taxi run to Station 15+00, using a pattern opposite the one used in the first aircraft test. At Station 15+00, he wheeled about, made a long takeoff run to Station 43+00, then lifted off.

After circling the area the pilot effected a hard landing on one set of main wheels at Station 15+00. He then eased the aircraft down on both sets of main wheels and rolled to Station 55+00, where he turned around. Next he made a high-speed serpentine taxi run to Station 15+00, following the serpentine taxiing tracks of the

first aircraft test. At Station 15+00 he turned around and made a serpentine taxi run back to Station 25+00, following the tracks of the serpentine run just completed. The pilot then took off on wheels between Stations 25+00 and 47+00 to complete the test at 1745 hours.

Observations

In the first test the aircraft was on skis for 3,000 feet and on wheels for 20,000 feet (12,700 feet while taxiing and turning and 7,300 feet while taking off and landing). The aircraft rolled freely and easily at all times. There was no evidence of the test on the surface of the area except for the 1- to 2-inch-deep wheel tracks in the drift snow.

In the second test the aircraft was on wheels for 36,000 feet (17,700 while taxiing and turning and 18,300 while taking off and landing). The aircraft rolled freely and easily at all times. It left 1- to 2-inch-deep wheel tracks in the drift snow on the area, but only faint tire prints on the compacted surface free of drift. Inspection showed that the surface of the area was only slightly scuffed where the aircraft landed on one set of main wheels. The long takeoff and landing rolls were made to simulate the takeoff and landing rolls of a C-121J aircraft.

During the two tests, the aircraft made four wheel landings, five wheel takeoffs, eleven backup turnarounds, and 31,000 feet of taxi runs. In all, during one 6-hour period, it trafficked the 10-70 area on wheels a total of 10.72 miles. The drifted portions of the 10-70 area were covered with 1- to 2-inch-deep tracks after the tests, but the drift-free portions were faintly marked with tire prints. These were hard to find even where the aircraft made three trips over the same area.

STRENGTH REQUIREMENTS FOR COMPACTED-SNOW RUNWAYS

Based on previous aircraft tests, tentative strength requirements for supporting heavy aircraft on wheels were developed for the DF-65 snow-compaction trials. As the trials progressed more precise requirements were determined.

Pretrial Requirements

The NCEL tentative minimum hardness guide for compacted snow[17] shows that an average Rammsonde hardness of 540 R in 12 inches of compacted snow and 480 R in 16 inches is required for marginal support of a heavy aircraft with its main wheel tires inflated to 95 psi. In the DF-64 trials[3] it was found that a 10-inch-thick layer of compacted snow with an average Rammsonde hardness of 470 R provided marginal support in a slow taxi test for an LC-130F aircraft weighing 104,000 pounds with the tires on its tandem main wheels inflated to 80 psi. The total resistance to confined shear in this 10-inch layer of compacted snow was 320 lb/in. for a load-carrying capacity of 80 psi (see Test Procedures in Part I).

Based on this information, the following estimated minimum strength requirements were developed before the DF-65 trials for a 16-inch-thick layer of compacted snow capable of supporting a C-130 aircraft with the tires on its tandem main wheels inflated to 95 psi:

Compacted-Snow Thickness (in.)	Rammsonde Hardness Index (R)	Total Resistance to Confined Shear (lb/in.)	Load-Carrying Capacity (psi)
12	540	-	-
16	480	380	95

Mininum Requirements From DF-65 Trials

6 December Test. On 6 December an LC-130F aircraft weighing 90,000 pounds, with the tires on its tandem main wheels inflated to 95 psi, made takeoffs, landings, and taxi runs on wheels on the 16-inch-thick DF-65 layer of compacted snow on the 10-70 area. After this test, examination of the area showed that the compacted snow failed under the main wheel load where its total resistance to confined shear was 356 lb/in. (load-carrying capacity 89 psi), but that it supported this load where its total resistance to confined shear was 452 lb/in. (load-carrying capacity 113 psi).

Confined-shear strength tests in these two areas and in two other areas of greater strength that were subjected to the main wheels of the aircraft showed the following results:

Depth Below Surface (in.)	Failure	Marginal Support	Fair Support	Good Support
	Confined-Shear Strength (psi)			
0-4	34	39	26	40
4-8	27	32	26	50
8-12	15	20	35	60
12-16	13	22	40	25
	Total Resistance to Confined Shear (lb/in.)			
0-16	356	452	508	700
	Load-Carrying Capacity (psi)			
0-4	34	39	26	40
0-8	61	71	52	90
0-12	76	91	87	150
0-16	89	113	127	175

The confined-shear strength in the top 4 inches of the compacted snow at these locations ranged from 26 to 40 psi; except in the area of failure, the wheel tracks at these locations were less than 1/2 inch deep. In other places on the DF-65 layer, during this test on the 10-70 area, the wheel tracks were 2 to 4 inches deep where the confined-shear strength in the top 4 inches was 15 psi or less. These areas, however, did not fail, since the load-carrying capacity of the DF-65 layer under the soft surface snow was 90 psi or more.

In the area of failure shown in the preceding table, the load-carrying capacity in the top 8 inches of the DF-65 layer was only 61 psi or about 65% of the main wheel tire inflation pressure. This, coupled with the apparent inability of the 13- to 15-psi snow in the bottom 8 inches of snow at this location to absorb or transmit the remaining load to the underlying DF-64 layer without compressing, resulted in a failure of the DF-65 layer. When this bottom 8 inches of snow compressed under the load, the top 8 inches sheared and disaggregated.

In the area of marginal support shown in the table the load-carrying capacity in the top 8 inches of the DF-65 layer was 71 psi, or about 75% of the main wheel tire inflation pressure. The 20 to 22 psi snow in the bottom 8 inches of the layer, however, was apparently sufficiently strong to absorb the remaining load with little or no compression, so no failure occurred in this location. The Rammsonde hardness in the top 12 inches of snow was 550 R; in the total 16 inches, it was 540 R.

In the area of fair support shown in the table, the load-carrying capacity in the top 8 inches of the DF-65 layer was only 52 psi or about 55% of the main wheel tire inflation pressure. The strength in this 8 inches of snow, however, was apparently sufficient to support its share of the wheel load without failing and to transfer the remaining load to the stronger snow in the bottom 8 inches at this location.

In the area of good support shown in the table, the load-carrying capacity in the top 8 inches of the DF-65 layer was 90 psi, or almost the same as the 95 psi inflation pressure of the main wheel tire. This, coupled with the strong snow in the bottom 8 inches at this location, provided ample support for the aircraft. The Rammsonde hardness in the top 12 inches of snow here was 750 R; in the total 16 inches it was 660 R.

Margin of Safety. Based on previous observations[3] and the area of failure described above, it appears that the minimum load-carrying capacity in a 16-inch layer of compacted snow for marginal support of an aircraft with tandem main wheels should equal the tire inflation pressure of the main wheels. Using this criterion, the three areas in the 16-inch-thick DF-65 layer of compacted snow cited above which supported the aircraft, provided some margin of safety in their support as follows:

Area	Margin of Safety (%)
Marginal support	1.19
Fair support	1.34
Good support	1.84

24 January Test. On 24 January an LC-130F aircraft weighing 125,000 pounds with the tires on its tandem main wheels inflated to 85 psi tested the 10-70 area. Thirteen times during this test one or the other set of main wheels punched into the DF-65 layer of compacted snow. These failures, which occurred directly under the wheels, resulted from processing misses in the compacted snow. In the area of failure, the aircraft was supported on a ski, but once the aircraft moved beyond the failure the wheels immediately regained the surface. Twelve of the points where the wheels regained the surface were examined for confined-shear strength after the test. These strength tests were made in the wheel track at the point of resurfacing, or that point where the mere print mark of the tire indicated support of the wheel. From these tests it was found that the average load-carrying capacity in the DF-65 layer of compacted snow where the aircraft regained surface support was 157 psi. It was also found that the point of maximum load-carrying capacity where support was regained was 237 psi, and the point of minimum load-carrying capacity was 90 psi.

The confined-shear strength and the load-carrying capacity in the four points of minimum strength where the main wheels of the aircraft regained the surface were:

Depth Below Surface (in.)	Confined Shear Strength (psi)			
	Example 1	Example 2	Example 3	Example 4
0-4	30.0	32.5	27.0	31.1
4-8	23.9	14.1	24.7	25.6
8-12	20.9	28.3	21.1	28.4
12-16	15.6	32.0	41.7	41.7
	Load-Carrying Capacity (psi)			
0-16	90	107	115	127

In the first example, the load-carrying capacity of the DF-65 layer was only 90 psi where one set of the main wheels regained the surface. This load-carrying capacity was only 5 psi more than the 85-psi tire pressure in these wheels. In the other examples, the load-carrying capacity of the snow was 22 to 42 psi more than the tire pressure. In examples 1 and 2 it is also interesting to note the existence of 4-inch-thick layers of compacted snow with confined-shear strengths of 15 and 14 psi. In previous tests, failures occurred where snow of this strength existed in the compacted snows.

PART V. SUMMARY

FINDINGS

Construction, Maintenance, and Repair

1. Adequate grading and leveling to assure uniform depth of snow cover before compaction is essential when adding a compacted layer over another compacted layer.

2. Processing-equipment windrows must be evenly spread before age-hardening to prevent longitudinal undulations.

3. Removal of drift on compacted snow with use of the snowplow carrier greatly accelerated this operation.

4. Drift should be removed before it age-hardens, and when compacted snow is completely inundated with a foot or more of drift, stakes should be used to provide a uniform plane of reference.

5. Use of a truck-tractor with high-flotation tires as a tow vehicle for maintenance equipment eliminated surface damage and increased the speed for towing equipment approximately tenfold.

6. Surface finishing with a drag was most effective when the snow temperature was at or near 32°F.

7. Poorly processed snow can be reclaimed by reprocessing.

Physical Properties of Snow

1. Three-pass processing with the model 36/42 mixer was as effective as four-pass processing in the natural snow on the Ross Ice Shelf near McMurdo Station.

2. Rolling for surface hardness increased the rate and amount of strength growth in compacted snow during age-hardening.

3. Reprocessing compacted snow increased average density from 2 to 5% but did not increase load-carrying capacity.

4. Patching poorly processed snow by reprocessing with the snow mixer produced load-carrying capacities near those of the well-processed snow in the DF-65 layer, but this strength lagged that of the original material by the time difference in processing.

5. Air temperatures influenced the temperature of compacted snow to a depth of 5 feet with a temperature lag of less than 6 hours.

Aircraft Tests

1. The compacted snow surface on the 10-70 area was smooth and provided good braking action.

2. Failures in between-mixer-lane misses were confined on each side by the well-processed snow in the DF-65 layer and at the 16-inch depth by the DF-64 layer.

3. Well-processed snow in the DF-65 layer supported a 125,000-pound LC-130F aircraft with main tire inflation pressures of 85 psi when air temperature was up to 32°F and snow temperature in the top foot was 23°F.

4. Minimum requirements for a 16-inch-thick layer of compacted snow for aircraft grossing up to 135,000 pounds with tandem main wheels and tire pressures of 95 psi are:

   a. An average confined-shear strength of not less than 20 psi at any depth in the compacted layer.

   b. A total resistance to confined shear of not less than 100 lb/in. in the top 4 inches of the compacted snow, 220 lb/in. in the next 8 inches, and 80 lb/in. in the bottom 4 inches.

   c. A confined-shear strength of not less than 25 psi in the top 4 inches, 28 psi in the next 8 inches, and 20 psi in the bottom 4 inches.

   d. A load-carrying capacity of not less than 100 psi in the 16-inch layer of compacted snow.

CONCLUSIONS AND RECOMMENDATIONS

1. Well-compacted snow is capable of supporting a 125,000-pound aircraft with tandem main wheels and tire inflation pressure of 85 psi during periods of air temperatures to 32°F and snow temperatures to 23°F. This same area will support a 135,000-pound aircraft with tire inflation pressure of 95 psi during periods of air temperatures to 18°F and snow temperatures to 16°F.

2. For safe operations on deep snow fields, a compacted-snow runway for aircraft grossing up to 135,000 pounds with tandem main wheels and tire pressures of 95 psi should be between 30 and 50 inches thick, and its total load carrying capacity should be twice that of the tire pressure.

3. Snow-compaction trials should be continued to assure strengths capable of supporting 155,000-pound aircraft with tire inflation pressure of 135 psi, and to more fully develop surface-hardening techniques and protective measures for the surface.

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13. ABSTRACT

The Laboratory conducted snow-compaction investigations on the Ross Ice Shelf adjacent to McMurdo Sound during Deep Freeze 65 following investigations made during Deep Freeze 61 through Deep Freeze 64. A 150- by 6,000-foot runway was constructed by adding a 16-inch layer of compacted snow over an existing layer. Construction was completed on 24 November 1964 and the runway was maintained and repaired for aircraft tests until 14 February 1965. Snowplow carriers used in clearing the runway of drift snow greatly reduced the time required for this operation over previous methods using a snowplane. A 6 by 6 truck-tractor with high-flotation tires served as a prime mover for maintenance equipment, and resulted in large savings in time over use of a size 2 snow tractor. This wheeled vehicle also eliminated damage to the runway surface caused by track vehicles.

The runway was tested early in the season by a 25,000-pound C-47J aircraft with tire inflation pressure of 60 psi; it was tested five times at approximately 2-week intervals by an LC-130F aircraft weighing from 90,000 to 135,000 pounds with tire inflation pressures of 85 to 95 psi. During the first LC-130F tests, intermittent failures occurred in the DF-65 layer of compacted snow due to misses between lanes of snow processed by the mixers and seams of unprocessed snow between the DF-64 and DF-65 layers. These low-strength areas were repaired by reprocessing with the mixers, which brought their strength up to that of the original DF-65 layer.

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